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## Journal of the Washington Academy of Sciences

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## Editor's Comments

### Special Section on Human Factors

This issue features two articles based on presentations at the Washington Academy of Sciences' Capital Science ("CapSci") conference in March 2012. The papers were presented on behalf of the Potomac Chapter of the Human Factors and Ergonomics Society (POT-HFES) mini-symposium at CapSci 2012, and they are:

- "Human Systems Integration (HSI): Psychological Influences in Design Produce Exceptional Operator Performance" by Gerald Krueger, and
- "Commercial Truck Driver Performance in Emergency Maneuvers and Extreme Roadway Conditions Presented in a Driving Simulator" by Justin Morgan and a highly-regarded group of researchers at Virginia Tech's Transportation Institute.

The Academy has featured a series of CapSci POT-HFES mini-symposia and follow-up articles in this Journal over the years. For those particularly interested in the topic, the former issues with multiple articles on the topic of human factors were dated: Summer 2006, Fall 2008, and Fall 2010. We thank Dr. Jerry Krueger for organizing the series of special issues and note that, as we're going to print on this issue, the U.S. Army MANPRINT Program is announcing availability of an upcoming Joint HSI display in the Pentagon ... so, clearly it's a timely topic!

### Articles and Follow-up

The third article of this issue, "Springs of Washington, D.C.: A Tale of Urbanization" by John ("Jack") Sharp, focuses on another important topic—changes to certain geological conditions that originally made the D.C. area attractive for settlement centuries ago. The background on this article extends back to the time of the nation's bicentennial, when Garnett Williams examined old newspaper files to locate the city's springs and understand the early water courses dating back to 1776. This research resulted in Williams' 1977 U.S. Geological Survey (USGS) Circular entitled (sadly) "Washington, D.C.'s Vanishing Springs and Waterways." As follow-up to that bicentennial study, the Geological Society of Washington sponsored a 2012 field trip to examine the modern-day sites of the long-ago "fresh brooks and streams" of the D.C. area. Our brief article is based on the recent field trip, about which Dr. Sharp commented, "I think the important thing is for folks to realize what is under their feet (and cars) and how it affects our environment ..."

We're pleased to share this eye-opening perspective, and think you'll enjoy learning from it. Thanks to Sandy Neuzil of USGS for her help and advice on the material.

### **Academy Business**

We also include in this issue remarks made at the Academy's May 15, 2013 annual meeting by outgoing president Jim Cole and incoming president Jim Egenrieder, along with a photo of our distinguished officers and board.

I'd like to invite members of the Academy community to contact me if interested in working with our interdisciplinary Journal staff on various roles. We are beginning a new search for individuals to serve on our Board of Discipline Editors. As always, we welcome ideas for special issues and manuscripts on topics of interest to our readership. We also welcome essays on current issues and letters to the editor on recent articles.

Last, but certainly not least, we're always happy to add to our great group of anonymous reviewers and volunteer proofers. We have a dedicated group of individuals who are devoted to the Journal's cause on an ongoing basis -- and we're truly grateful for their help -- and, at the same time, we also appreciate fresh views and energy!

For help with this issue, we thank Professor Katherine E. Rowan, Director of the Science Communication Graduate Program at George Mason University (GMU); Elizabeth Grisham, student in the same GMU program; and Emanuela Appetiti of the Institute for the Preservation of Medical Traditions. Thank you, again, to all.

Sally A. Rood, PhD, Editor

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## **Erratum in the Winter 2012, Vol. 98, Issue 4**

**Albert Gerard Gluckman**, “Methods to derive the Einstein partial differential equation describing the ray optics and kinematics of his light ray path experiment with moving mirror,” pp. 47-62.

**(a) Section 4 on page 52**

**Was:** “This assignment simplifies equation (5)”

**Should be:** “This assignment simplifies equation (7)”

**(b) Section 4 on page 52**

**Was:** “Applying the chain rule of the differential calculus to the terms in equation (6) yields”

**Should be:** “Applying the chain rule of the differential calculus to the terms in equation (8) yields”

**(c) Section 4 on page 53**

**Was:** “Therefore, equation (9)”

**Should be:** “Therefore, equation (11)”

**(d) Section 5 on page 54**

**Was:** “Upon substitution, equation (10)”

**Should be:** “Upon substitution, equation (12)”

(e) Section 5 on page 55

The appearance of the array at the top of the page is:

-----

$$\tau(x',i_5) \sim \tau(H,K) - (x'-H)\delta_H\tau(H,K) - (i_5-K)\delta_K\tau(H,K)$$

-----

→

$${}^1\tau(0,i_4) \sim {}^1\tau(H,K) - {}^1\tau(0-H)\delta_H\tau(H,K) - {}^1\tau(i_4-K)\delta_K\tau(H,K)$$

-----

$${}^2\tau(0,i_4) \sim {}^2\tau(H,K) - {}^2\tau(0-H)\delta_H\tau(H,K) - {}^2\tau(i_4-K)\delta_K\tau(H,K)$$

-----

where the vertical dashed line (it has two dashes) in the third line from the top is actually an equal sign. There are two such equal signs. The arrow points to the first one.

(f) Section 6 on page 56

- Was: “Equation 14”
- Should be: “Equation 16”
- Was: “Equation 15”
- Should be: “Equation 17”

(g) Section 6 on page 57

- Was: “which after substitution of equations (7) and (8), takes the form of equation (9),”
- Should be: “which after substitution of equations (9) and (10), takes the form of equation (11),”

Washington Academy of Sciences

**(h) Section 7 on page 57****Was:** “([3] see his ref. 4, ch. XI, p. 173)”**Should be:** “([3] see ch. XI, p. 173)”**(i) Appendix on page 59****Was:**  $v = \frac{1}{4} c$ **Should be:**  $v = \frac{1}{4} c$ **(j) Diagram 2 in the Appendix****Was:** In the sentence starting with “Comparison of numerical results from ...moves away from ...”**Should be:** In the sentence starting with “Comparison of numerical results from ...moves towards ...”

The equation that follows this sentence has an error. The following equation is correct.

$$\tau_1 = 2.\overline{6} \times 10^{-5} + \frac{0.75 \times 10^5 (10)}{(9.0 - 0.5625) \times 10^{10}} = 3.\overline{5} \times 10^{-5} \text{ sec}$$

**(k) Bio on page 62**

**Was:** Dr. Gluckman is the author of seven monographs published by the Washington Academy of Sciences. They cover the evolution of electrical experiments over a 200 year period. He has also published 32 peer reviewed papers in many journals including the Proc. IEEE, the Am. J. Physics, and the Matrix and Tensor Quarterly. He prepared a replica typescript for the Joseph Henry papers of the Smithsonian that used the written notes of Henry on oscillatory current (1836 – 1842). He also worked with NASA and DoD on edge diffraction and multiple reflections of microwaves over terrain.

**Should be:** A. G. Gluckman is the author of the 7th monograph published since 1898 by the Washington Academy of Sciences.

The book is an annotated bibliography of experimental studies of electrical science and technology over a 200 year period. It was reviewed by an editor from **The Joseph Henry Papers** of the Smithsonian. After retirement from Federal Service with NASA and DoD, he taught mathematics as an Adjunct Professor at the University of the District of Columbia.

---

# **Human Systems Integration (HSI): Psychological Influences in Design Produce Exceptional Operator Performance**

**Gerald P. Krueger**

**Krueger Ergonomics Consultants, Alexandria, Virginia**

## **Abstract**

During the past two decades, that portion of human factors and ergonomics work centered in materiel acquisition settings has been largely subsumed into the larger context of “human systems integration” or HSI – where such work has taken its rightful place as an important part of systems engineering and management processes (Booher, 2003). Human systems integration focuses on ensuring all human elements are properly accounted for in research and design initiatives when developing large configurations of people-operated equipment and systems. HSI evolved from practical applications of established human-oriented design principles espoused in the fields of engineering psychology, human engineering and macro-ergonomics – disciplines predominately pioneered in military acquisition programs since World War II. HSI is also now more widely employed in procurement of large new civilian systems of people and machines in such diverse applications as new transportation, communication, finance and banking, and homeland security systems design, as well as the diverse designs of hospital surgical wards and treatment centers. This article describes the derivation and basic premises of incorporating engineering psychology into HSI. It also presents a few practical contemporary examples of the application of psychology in HSI.

## **Introduction**

**ONE CANNOT ADEQUATELY DESCRIBE** the early derivation of HSI without pointing out the role of engineering psychology in military materiel system development processes. Since World War II, engineering psychologists contributed immensely to the design of complex, sophisticated equipment and weapon systems to ensure that military personnel operate at optimum levels in training and combat. Engineering psychologists not only do superb human sciences research, but as practitioners, serve as key consultants advocating for system users (soldiers, sailors, airmen, and marines) in the materiel systems engineering and development process. Human factors specialists bring in-depth appreciation and prediction of how human operators will perform on new high-technology systems – often under stressful working conditions, in harsh environmental extremes, occasionally encountering information

overload, in time-sensitive settings requiring quick, accurate decision-making, where failure is not an option.

While these attributes certainly pertain to military settings, there are close parallels in numerous civilian applications when considering the jobs of: human operators in airline transport of cargo or passengers; next generation air traffic control; municipal rapid transit systems; intelligent highway systems; bridge and roadway toll systems; processing computerized banking and finance services; providing hospital, police, fire, ambulance and other first responder services; maintaining public utilities such as nuclear power reactors and regional electrical grids, water purification and sanitation plants; activating homeland security systems; aerospace systems, and even initiatives in national intelligence networks and efforts to prevent cyber-terrorism.

### **Engineering Psychology is Key to HSI**

*Engineering psychology* is a scientific discipline that elucidates and predicts the performance of individuals and teams while they carry out tasks on their jobs – usually operating or maintaining equipment (*e.g.*, vehicles, communication and computer systems, weapons, plant control centers and more). Engineering psychologists possess good grounding in applied experimental psychology, cognitive engineering, experimental design and statistics. They usually conduct human experiments to measure performance in attempts to determine the best ways to design human-operated equipment and systems, as well as to streamline preferred operating procedures with a goal of optimizing human-system performance (*e.g.*, being user friendly, not error-prone, without incident or accident, and facilitating design to achieve desired operator performance of the system). Through their research engineering, psychologists establish generalized, predictive human performance principles to advise project management designers about how humans will perform in operating future systems still being developed. One of the simplest examples in deciding function allocation in systems design may be for the psychologist to help determine “what people-are-better-at,” versus “what machines-are-better-at” in performing certain tasks (*e.g.*, determining appropriate amounts of automation, perhaps related to the proliferation of robots and unmanned ground vehicles, and remotely piloted air systems such as “drones” in homeland security surveillance or on contemporary battlefields).

Engineering psychologists often work as part of multidisciplinary system-design teams, which may include specialists in anthropometry,



physiology, biomechanics, job task analyses, or safety engineering. They often work in collaboration with design engineers charged to consider all the human variables in their new systems. The work, all of it devoted to better design for humans, takes on broader titles of “human engineering,” “human factors engineering,” “ergonomics,” “human-centered design,” “human systems design,” or simply “human factors.” The titles, with the exception of “ergonomics,” are often used interchangeably. The term *ergonomics* derives from the Greek *ergon*, for “work” (in physics, the *erg* is a unit of measurement indicating expenditure of energy), and from *nomos*, meaning “law.” Ergonomics, then, is the study of the laws of people expending energy at work – examination of the relationship between humans and their working environment (Murrell, 1965).

Initially centered in Europe and in Japan, ergonomics research stressed physiological, biomechanical, and anthropometric studies to seek efficiencies of people at work. Soviet Russians sought to integrate labor safety and health factors to become part and parcel of machine design, to progress past considering safety engineering as an addition or an afterthought, but rather as safe engineering design from the outset (Zinchenko and Munipov, 1979). By some contrast, engineering psychologists and human factors specialists, originally centered mainly in the United States, initially focused more on the sensory and cognitive aspects of work: sensation, perception, visual processes, information handling, decision-making, and so forth. This prompted advocates to say engineering psychology in the United States focused more on behavior from the neck up (Meister, 1971, 1999).

The unique contribution of engineering psychologists to system-engineering teams is that psychologists are trained to conduct experiments examining human performance. In particular, psychologists are best equipped to design studies that account for the trickiest of human performance variables: (a) individual differences (people behave and operate differently); (b) learning and skill development (people improve with repetition, they learn over time, and they can be trained); (c) motivation (people are moved to action by different incentives, they become bored with monotonous work); and (d) people can and will work in teams, with leaders and followers, sharing a workload and supporting one another in accomplishing a mission. While holding unique roles in designing experiments, engineering psychologists who are persuasive in portraying their compelling experimental data often exude leadership; consequently, they not only influence system-design decisions, they often take on key managerial roles for multidisciplinary teams.

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## **Influence of World War II**

The early history of engineering psychology or “human factors” is traced to military and industrial work done between World Wars I and II. Human factors research and testing initially focused on improving the production line, and the selection of personnel to fit the task – finding the right person for the job. By contrast, World War II provided a significant impetus to interdisciplinary investigations aimed at finding optimal conditions for people’s activity and the limit of human possibilities. Complex military hardware and weapon systems often made excessively heavy demands on operating personnel, far beyond human psychophysiological capabilities (Zinchenko and Munipov, 1979). Rapid technological developments such as radar, sonar, and high-speed aircraft produced some situations in which no amount of selection and training could enable an operator to fully exploit the potential of his/her equipment. The demands of World War II military technology provided a new and unifying focus for engineering psychology and human factors work, as it became necessary to “fit the job to the man,” to design equipment and systems with human potentials and limitations in mind. The subject matter of research was couched in terms of “adaptation of the machine to the person” and posed the question: Which human properties should be taken into account in building a machine for the person to operate? The focus changed to fit the machine tasks to a large number of prospective human operators.

During World War II, hundreds of psychologists left academic positions to support the war effort. A significant portion of them performed studies aimed at designing, testing, and evaluating military equipment systems. At the end of that war, the nation demobilized, and psychologists returned to their academic laboratories. But the transition to “Cold War” efforts saw the U.S. government in-house and extramural engineering psychology programs (*i.e.*, by adding programs at university and government captured research centers) grow dramatically, especially from 1946-1953; and again in the early 1960s. In 1957, the Soviet Union launched the first Sputnik satellite. That event so surprised and shocked the American public that it fostered a spectacular growth in federal support for science and technology, especially in the aerospace arenas. It included the segments of human factors engineering research perceived to have relevant contributions to make (Alluisi, in Taylor, 1994). For a brief history of the growth, and the particular missions of pertinent military research laboratories, see Chapanis, Garner and Morgan (1949), Chapanis (1999), Meister (1999), and Krueger (2012).

---

## Human Factors Research, Post-World War II

From 1950 to 1970, a substantial amount of military engineering psychology research was conducted at numerous government in-house and other federally funded research facilities. Parsons (1972) comprehensively reported dozens of those research efforts, which he dubbed “Man-Machine System Experiments.” Parsons described these as laboratory-based studies of multi-person situations, but also man-machine interactions, consisting of tasks in operational system settings responding to complex environmental stimuli, and for which the research methods included manipulation, replication, control of variables, collection of objective measures of human performance and quantification of results.

Man-machine system experiments relied extensively on simulation, and because they involved human operators as participants, they were distinct from simulations performed entirely on computers. Some of the research was done within four walls, but frequently the laboratory was actual military terrain designated and instrumented for experimental purposes. Some of the man-machine experiments sought knowledge about a particular system, a piece of equipment, a training technique, operator procedures, or certain conditions affecting human performance. Other experiments tried to acquire generalizable knowledge about the way humans perform in system settings. How do operators and managers make decisions? How do they develop their standardized procedures? How do they communicate with each other? For details and pointers on how to design complex human-machine system experiments, consult Parsons (1972).

### The Profession Comes of Age

During the 1950s, in the United States, rapid growth of the new discipline was apparent in two ways. First, numerous engineering psychology studies were published in the open literature, as these were coming out of military research labs, and from university research programs sponsored with military research funding (*e.g.*, from organizations such as the Office of Naval Research). Maturing industrial research centers (*e.g.*, Bell Telephone Labs *et al.*) also published significant human factors work.

Second, to represent the science of human factors engineering, two professional societies were formed in the United States and one in Europe. On the U.S. East Coast, engineering psychologists with common affiliation promoted identification of their profession by forming, in 1956,

a new Division of the American Psychological Association: Division 21, the Society of Engineering Psychologists (now called Applied Experimental and Engineering Psychology). Over the decades since then, Division 21 members, active-duty military officers, defense civil servants, academicians and other defense contractors accomplished significant amounts of engineering psychology research. Their results had both military and civilian applications. Some of the most productive and prominent among them are written about in Taylor's (1994) treatise, "Who Made Distinguished Contributions to Engineering Psychology." A new journal was initiated, currently entitled: *Experimental Psychology: Applied*. Today Division 21 now has approximately 300 psychologist members.<sup>1</sup>

In Southern California, seat of the aircraft and aerospace industries, persons interested in the new emphasis on human factors research formed the Human Factors Society (HFS) in 1957. With it, they introduced the journal *Human Factors*. The HFS accepted as members anyone who worked in the multiple areas of human factors – areas dealing with considerations of human factors that influence the design and operation of systems, including human-machine interfaces, product and workspace designs, and safety. In the beginning, almost half of HFS members were psychologists. However, HFS has never been viewed as a "psychological society." In 1992, HFS was renamed the Human Factors and Ergonomics Society (HFES) and it currently has over 4,500 members; perhaps fewer than one-third identify themselves as psychologists. The research and practitioner backgrounds of the HFES membership are varied and the professional society is very much an interdisciplinary one. For a history of the formative years of the HFES, see the *Chapanis Chronicles* (1999).<sup>2</sup>

Meanwhile in Europe, the term *ergonomics* was adopted in Britain in 1950, when a group of British scientists organized the Ergonomics Research Society (ERS) as a joint European endeavor of physiologists, psychologists, anatomists, engineers and designers. The name ergonomics was selected because it did not derive from any one of the disciplines, but rather encompassed portions of each of them. This professional affiliation prompted significant amounts of quality research on human-systems design. Its members and international colleagues published prolifically in the long-standing journal today entitled, *Ergonomics, the International Journal of Research and Practice in Human Factors and Ergonomics*.

During the 65 years since World War II, the several professional human factors and ergonomics communities crisscrossed the oceans, gradually merged most of their philosophies, and eventually changed the names of their professional societies to encompass both camps. In 2009, the Ergonomics Research Society changed its name to the Institute of Ergonomics and Human Factors (IEHS)<sup>3</sup> (Waterson, 2011). Practitioners today use combined titles, readily identifying themselves as human factors and ergonomics specialists.

### **From Human Factors in Army MANPRINT to Human Systems Integration**

Human factors specialists, working as members of multidisciplinary teams on the development of military systems, often conduct experiments and field studies with soldiers, sailors, airmen and marines. For half a century, the results of their work were directed into Department of Defense materiel acquisition decision-making forums where the major question usually is whether to pursue further development and/or to advance to the production procurement step for new weapons and other materiel systems. In such acquisition arenas, the distinctive label of “professional researcher” is often lost. Anyone who serves as the advocate for soldier performance (or that of any user/operator/maintainer), and represents operator/user concerns, is normally identified as the “human factors representative” in the system design process.

An overriding aim of the engineering psychologist, or the human factors specialist, is to do more than just assist system designers to “meet threshold requirement design criteria” (usually stated in minimal performance expectations for the new system to meet envisioned missions). Rather, his/her goals include performing research that will “enhance” operator performance of these systems. Each of the four U.S. military services has its own system for incorporating human performance data and other human factors findings, to assure procurement of the best human-machine systems design possible. All human factors shortcomings identified during operational testing with ultimate user representatives are to be resolved through redesign or retrofit. Alternatively, risks are to be mitigated in some other way, such as by altering the operator procedures or by embellishing operator training before procurement decisions are finalized. Another one of the goals of human factors specialists, then, is to affect design decisions as early in the research and development cycle as practical, so as not to require making “fixes” or “retrofits” to problems later, which might be identified prior to (or even after) procurement and

fielding. Meeting this later goal of having an early impact is a frequent challenge, because in dynamic settings, design requirements continually change.<sup>4</sup>

In assessing the successes of a dozen or more major weapon-system and civilian high technology development programs, Booher (2003) concluded that there is little question of the positive value of employing human factors engineering in producing safe and effective products and systems. However, in the 1980s, even after years of research and development and operational testing had been done, several new U.S. Army major equipment systems exhibited significant operator performance problems. To determine “what went wrong,” the Army conducted reverse systems engineering analyses to establish “lessons learned,” in hopes of improving subsequent equipment development programs. This effort was spearheaded by General Maxwell Thurman, who at the time was the Army’s Deputy Chief of Staff for Personnel. In 1986, General Thurman formalized those lessons into the Army’s Manpower Personnel Integration (MANPRINT) program – a human operator-oriented systems engineering management and technical program destined to improve the design of weapon systems and military unit performance.

In initiating MANPRINT, the U.S. Army was the first organization to fully implement and demonstrate the benefits of a comprehensive human systems integration (HSI) approach. General Thurman, the fiercest proponent of MANPRINT, coaxed Army leadership into changing the focus of equipment developers away from “equipment only” and more toward a “total system” view – one that focuses directly on the human elements as critical components of the system. The new focus recognized the human operators as the primary reasons for designing, developing and deploying a system. Henceforth, Army Acquisition was to consider soldier performance and equipment reliability together as a system.

The MANPRINT program is very broad, and includes all Army management, technical processes, products, and related information covering six domains.<sup>5</sup> These six domains are:

- 1) Manpower (to identify the number of people needed to operate and maintain new systems)
- 2) Personnel Capability (to identify the skill sets needed)
- 3) Training (for both new equipment and sustainment)
- 4) Human Factors Engineering (HFE)
- 5) System Safety, and

- 6) Health Hazards (exposure to operators and maintainers of the systems under development).

After the Persian Gulf War of 1991, a seventh domain of Soldier *Survivability* was added. The Survivability domain considers characteristics of the system that can reduce fratricide, detectability, and probability of attack, and includes minimizing risks of personal injury and cognitive and physical fatigue. The unique aspect of the MANPRINT program was its effective integration of human factors into the mainstream of materiel system definition, statement of requirements, development and deployment (Booher, 2003).

Eventually, the U.S. Navy initiated a similar program, entitling it SEAPRINT for Systems Engineering Acquisition and Personnel Integration, which basically contains the same domains, but instead of survivability identifies a *Habitability* domain, combining some elements of HFE, safety, and health hazards for onboard-ship considerations. The U.S. Air Force briefly flirted with its own proposed AIRPRINT version, again with slightly different domain names. However, the effort was cut somewhat short when, in 2001, the Department of Defense issued mandatory procedures for major defense acquisition programs, which were to adhere to the newly formalized *Human Systems Integration* (HSI) concept which programmatically identifies most of the domains of MANPRINT. Some of the DoD HSI elements, such as System Safety, which includes Occupational Health and Health Hazards Assessment, are less clearly delineated, as their descriptions are embedded in other portions of very voluminous acquisition documents (*i.e.*, DoD 5000.2R June 2001; DoD 5000.02, December 2008).

Subsequent evolution of military HSI applications found human factors specialists involved in addressing new questions posed by the acquisition teams, especially regarding system life cycle cost projections. As was traditionally the case, human factors specialists continued to help resolve important human design decisions, such as critiquing human engineering designs of individual crew served weapons (*e.g.*, How many crew members are required to operate an individual tank? or Should a helicopter cockpit accommodate two pilots seated side-by-side versus positioning them in tandem front-back seating?). Now under HSI, human factors specialists interact with other project analysts to account for such Manpower and Training human-related considerations as: How many troops will be needed to staff a whole battalion of combat vehicle operators and maintainers over a decade of training and warfare? What



will it cost to offer new equipment training to hundreds of soldiers to operate a new weapon system and to offer sustainment schoolhouse training to thousands more newcomers over a decade? Some specialists would label such work as macro-ergonomics.

### **Applications of HSI in the Non-Military World**

In December 2010, in recognition of the growing stature and importance of HSI in the nation's science base, the National Academy of Sciences' National Research Council (NRC) elevated the long-standing *Committee on Human Systems Integration* to the level of a board, and it is now the *Board of Human Systems Integration* (BOHSI). This newly acquired national Board stature adds recognition of the importance of HSI for all government agencies. It helps promulgate its importance into industry and commerce as well.<sup>6</sup>

HSI methodologies work best for organizations whose acquisition programs are developing large systems of people and equipment. Beyond those methodologies in place in military acquisition programs, there are numerous other examples where HSI has been (or should be) adopted. Several federal agencies beyond DoD have already either adopted many tenants of HSI or are presently evaluating the DoD HSI model(s) to assess which portions would work well for them, with the intention of adapting selected portions deemed of benefit to them. Such agencies as the Department of Transportation and its Federal Aviation Administration, numerous agencies in the Department of Homeland Security (e.g., its U.S. Coast Guard), the U.S. Postal Service, and others have obvious need for such systems engineering approaches. Some examples of non-DOD applications of human-machine interaction studies, both in government equipment procurement and in industrial applications procurement, can be found in the recent book on human-centered design edited by Guy Boy (2011).

### **The Need for Culture Change**

Booher (2003) wrote that HSI is very attractive as a new integrating discipline that can move business and engineering cultures toward a people-technology orientation. Human factors and ergonomics are necessary fields for successful implementation of HSI. However, they are not sufficient in either military or civilian acquisition applications, because they do not fully cover other important human domains that need representation, and because of their general inability to significantly influence organizational decision-makers. To be effective, the needed



culture change must start with organizational leadership. At the heart of the need for a cultural change in business and engineering is the fact that HFE, as a people/technology interface discipline, has, by itself, been largely ineffective at changing ingrained attitudes in government and in most industries. If organizations are to change significantly to take advantage of the benefits offered by HSI, top management needs to require that human factors principles are utilized. Boorer (2003) should have added that the “HSI theme” also needs to be institutionalized. He wrote that, even when the benefits of human factors are fully appreciated by top leadership, the influence on systems acquisition tends to erode with changeovers in leadership (Booher, 2003). Newly arrived leaders must be educated to the merits of the HSI approach. At least on paper, military acquisition policies attempt to ensure that adherence to HSI principles carries through changeovers of leaders and are therefore more likely to have a positive impact on the next similar system development within the same office. However, this is not guaranteed, and organizational downsizing, significant budget decreases, and changes in acquisition policies loom as perennial threats to the notion of institutionalizing the beneficial features of the HSI process.

Some of the same organizational concerns were also highlighted by a U.S. National Research Council (NRC) committee addressing issues facing the HSI community within systems engineering (Pew and Mavor, 2007). The committee offered suggestions on how to succeed in the currently evolving systems engineering environment. This is an environment that prizes risk-identification and management and incremental and spiral development,<sup>7</sup> and also one that employs iterative designs, implements revolutionary software design tools and methodologies, and fully engages in an incremental commitment model of development. The NRC committee fosters the creation of more synergy between HSI research and practice to make practitioners more aware of relevant research and better inform researchers about the insights and body of knowledge gained from practice (Pew and Mavor, 2007).

The NRC committee’s numerous conclusions and recommendations should promote discussion among HSI proponents and spur human factors and ergonomics practitioners into action. If we are already engaged in the materiel acquisition transformation process, and have not done enough about the NRC committee’s recommendations, soon we will be left with the existing esoteric approach to system design -- and which will have been by-passed a decade ago (Krueger, 2007).

In her recent presidential address to the Human Factors and Ergonomics Society, Mica Endsley said: “To make real inroads into the systems engineering design process, human systems engineering needs to be clearly recognized along with other engineering professions as a key participant in the development of system requirements, as a contributor during the system design process, and as a mandatory requirement for system test and validation.” (Endsley, October 2012). Thus, Endsley repeats the refrain that “early participation” in the system concept phases – and especially in the specification of the system design requirements phase – is of paramount importance for HSI and human factors practitioners.

### **Practical HSI Examples of Retrofitting New Equipment into Extant Systems**

In my own human factors career, I gained much personal experience in accomplishing HSI assessments and recommending practical human factors solutions to identified problems. To illustrate a few recent experiences, I offer here two examples of designing new systems or retrofitting new equipment technologies into existing materiel systems.

#### ***Smoothing Out Border Crossing Security Screening***

The first example (of retrofitting) involves an attempt to assist the U.S. Customs and Border Protection (CBP) agency with the addition of radio-frequency identification (RFI) chip technology into automobile drivers’ ID cards in order to smooth out the border-crossing process between the United States and its neighbors, Canada and Mexico. There were numerous human factors issues associated with the installation and operation of new RFI tracking technologies. New security screening equipment had to be integrated into an existing border-crossing security system. One of the major tricky human factors questions concerned how best to “train” a wide diversity of border-crossing travelers – who possessed different reading levels and operated with different native languages – to intuitively understand “how and where” to present their newly acquired RFI cards to engage the security screening tracking system as their vehicles passed through the queue in front of the CBP officers’ booths at the borders.

The CBP complaint initially was that hundreds of drivers in the queues were literally waving their cards at anything on posts or bollards that looked like possible “card readers.” Consequently, properly executed

compliance numbers were only around 10% successes. The human factors solution we eventually worked out was to mount on each RFI antenna a sign with a drawing of a generic hand illustrating how to hold the card. The placard had to be a weather-proofed adhesive sign containing an instructional depiction of how to hold the card without fingers occluding the RFI chip. It had to prompt travelers driving through the border access lane to display the card immediately in front of the actual RFI antenna arrays. The simple instruction to “point your card here” was posted in English and French at the Canadian border, and in English and Spanish at the Mexican border. This simple, straightforward human factors solution increased successful traveler compliance to well over 55% during the first week of deployment (a sizeable improvement in a short amount of time).

Other human factors measures that were adopted included posting instructional signs well in advance of the border crossing where travelers could read the instructions as they advanced through the queues. Within a matter of months, this hand-sign solution, among countless others, was employed at over 100 U.S. border crossings.

The series of four photos depict: a typical traffic backup of travelers in automobiles waiting their turn for security screening at a border crossing (Figure 1); installation of vehicle tracking systems including RFI antenna arrays to read travelers RFI-embedded ID cards (Figure 2); a close-up view of the weather resistant instructional sign installed to tell travelers where to point their RFI cards to properly activate the tracking/screening system (Figure 3); and a wide-angle view of multiple approach lanes to a representative border crossing, wherein each lane queue was equipped with the new instructional signs (Figure 4).

### ***Reengineering Soldier-Worn Computer Systems***

My second practical example is depicted in a single photo (Figure 5) showing a prototype version of the U.S. Army’s Land Warrior computerized infantryman system (*circa* 2002). In this new innovative fighting system, the Land Warrior soldier was to be equipped with: a belt-worn full-up computer system; a helmet-mounted display depicting a color map; a head-mounted set of night vision goggles; a daylight video capture system on his rifle; a GPS locator; a local area network short-range communication system; a multi-function laser feature; an integrated protective body army vest with ceramic plates; specialized uniform apparel; weapons; ammunition; vital essentials such as water and first aid kit; spare batteries; and more.



Figure 1. Typical queue awaiting screening at border crossing (photo by the author on CBP project research)



Figure 2. Tracking devices, RFI antennas at border crossing (photo by the author on CBP project research)



**Figure 3.** Instructional card solution produced traveler compliance (photo by the author on CBP project research)



**Figure 4.** View of multiple border approach lanes with signs (photo by the author on CBP project research)



**Figure 5.** Prototype computerized Land Warrior infantry system (photo provided by Program Executive Soldier Office, Fort Belvoir, VA)

Talk about soldier loads ... whew! This new soldier system was designed to provide not only significant amounts of additional fighting capability to the individual infantryman, but also enhanced capability for his 11-person squad, the 40-person platoon, and on up the chain of command to a 600+ person infantry battalion. Just imagine how many replacement batteries are required to provide the necessary power for a battalion to operate such technologies in the field.

There are still numerous human factors and human systems integration challenges to be resolved in designing such equipment, the interfaces among them, the trade-offs necessary because of much-added weight for the soldier to carry – and all with the overriding goal of making the systems soldier friendly and useable in accomplishing an infantry mission. Our Human Factors team accomplished numerous assessments,

did field tests and *fightability exercises*, and provided substantial recommendations for iterative design modifications and trade-offs as we participated in many multidisciplinary decision meetings over a decade of system development efforts.

The Land Warrior system promised to revolutionize infantry fighting operations, and was clearly headed that way. However, there were occasional times of awaiting even more sophisticated technological innovations, and then experiencing impending funding shortfalls, which prompted directional changes in the program. The Land Warrior has since morphed into successor programs. No doubt one day we will see a variant of this infantry system fielded by the U.S. Army.

### Summary and Conclusion

This section summarizes the salient points made in this treatise through several sets of bullets centered around: (1) the key HSI points and issues; (2) the HSI role in contemporary systems design engineering; and (3) the HSI messages to heed. The summary section is followed by a discussion of the problems in applying HSI.

First, the key points and issues made about HSI are these:

- HFE&E (human factors engineering and ergonomics) is necessary for good design but, by itself, is not sufficient to affect organizational decision-makers.
- Engineering psychologists know how to do good human factors research (which also, by itself, is not sufficient, often takes too long, and is too late to impact system design decisions).
- Researchers must strive not just to meet system *threshold requirements*, but rather to *enhance* human performance beyond expectations.
- As an attractive integrating discipline, HSI can move business and engineering cultures toward a *people-technology* orientation.
- A cultural change is needed: top managers must require human factors principles be incorporated from the conceptual phase of system design.
- The HSI process must be institutionalized, due to frequent changeovers in leadership.



Second, the HSI role in contemporary systems design engineering is summarized as the following:

- Contemporary Systems Engineering prizes these methodologies: (a) risk-identification and management; (b) incremental and spiral development (evolutionary design); (c) iterative designs (successive small improvements); (d) revolutionary software design tools and methodologies; and (e) the incremental commitment model of development.
- HSI practitioners must be better attuned to trends in the above areas.
- HSI researchers must couch research findings in non-esoteric language that practitioners can bring to the design and decision-making table for consideration.

Third, the HSI messages to heed are listed here:

- More synergy is needed between HSI research and practice.
- HSI practitioners must be more aware of and understand relevant research results for use in systems design and applications work.
- HSI researchers must design studies to directly answer system-relevant questions, or risk producing irrelevant results.
- HSI practitioners must engage in the current materiel acquisition transformation process, or risk falling significantly behind.

The bullets in Box 1 below, Problems Applying HSI, are presented as “food for thought.” The box presents a list of the problems that systems engineering designers must continually grapple with if they are going to be successful in taking advantage of the possible benefits HSI can offer them in system development.

The first issue/problem identified is to determine: “Who” is actually in charge of the design of the eventual system. It is necessary to grapple with considerations such as “the customer is always right, even when he is not.” Issues might include: Is it appropriate for the system developer to design the system to specifically meet and match the design requirements exactly as specified in the contract – without sufficient regard to perhaps offering better innovative designs not envisioned at the time the specs were written? Some technologies advance quickly, and new approaches should be considered. To this situation, it is incumbent on both the system designer and the “customer” to share ideas and negotiate



solutions to satisfy both parties. This is especially the case when the decision will affect the ultimate user of the system: *i.e.* the system's human operators.

### **Box 1. Problems Applying HSI**

- Who is “in charge” of design (and, therefore, of HSI) in acquisition? System engineer/designer? Government procurement agency? Vendor?
- The government competition fair policy can generate systems that are not necessarily ready for prime time.
- Retrofitting is more cumbersome and costly than doing it right from the outset.
- Add-ons to extant systems do not always make for smooth functioning; sometimes they exacerbate problems.
- Trade-offs are made everywhere. Some are helpful and succeed; some are not, and make matters worse.
- Military and other government procurement systems involve lengthy processes.
- Non-military agencies and industries are still grappling with which acquisition model and features of DoD-oriented HSI to adopt.

The second issue involves the notion that – at least in our federal government procurement actions – adherence to a “competition fair” procurement policy permits too many vendors to put forth systems they developed which are not yet ready for prime time. Some first models of systems really constitute brassboard or breadboard models of what might be possible if more years of work and funding were available to produce a fieldable product. This would necessitate stretching out procurement schedules much longer than they should be, and would likely result in cost overruns.

The third issue, concerning retrofit, is that occasionally proposed systems are quickly procured even before they are adequately tested to demonstrate sufficient performance. Then, the notion is often, “Well, we can always upgrade or fix this or that problem later” when offering a product upgrade after fielding. This, too, is a risky procurement avenue. Often it becomes more troublesome and costly to retrofit a system that was not designed properly the first time around. This is obviously a risk-management issue for procurement officers; however, giving due

consideration to human operator issues when making such trade-off decisions would be of paramount importance.

Regarding retrofitting, the fourth issue is that it should be recognized that adding in new technologies to extant operational systems usually causes many more “hiccups” than procurement officials envision when making decisions to do it. Consider just one example: When inserting a new sub-system into an operating control center, the operators in that center must usually maintain cognizance over old legacy systems still operating in place. At the same time, they must learn the newly arrived systems (probably via one-time visits from the new systems trainers/technicians). The seasoned operators must also train the new operators to master both the legacy systems and the new systems. Newcomer replacement personnel are not likely to be school-trained on the older systems because the schoolhouse moved on to teach the new systems, and classroom training time is limited. Thus, the workload for both seasoned hands and replacement personnel is significantly increased beyond that envisioned by most procurement officials.

Mastering trade-off decision-making is where most successful system designers earn their keep. Hopefully, such trade-off managers will take advantage of the consultation provided by a seasoned HSI practitioner who can offer insights and accurate predictions about how the eventual human operators will succeed in managing new systems.

As the sixth bullet implies, too many development efforts for large people-machine systems take excessively long before procurement is enacted. It is incumbent on all parties to streamline procedures, including HSI whenever possible, to conserve resources and ensure the fielded systems have not already passed by the original intent to procure them.

The seventh bullet suggests that when government agencies (and industry, too) examine the successes and failures of the evolving military and DoD HSI programs, it will be difficult to decide which attributes and procedures to adopt into their agency HSI model for incorporation into their own acquisition and procurement system.

After doing human factors work for more than 45 years in different venues, it is apparent that the challenges of incorporating customer/user advocate representation in the design and fielding of large people-machine systems are becoming more prevalent and important to society at large. Newer attempts to resolve human-related issues can be envisioned as new technology systems affecting large swaths of society are currently being

designed or redesigned. The need for HSI applications is apparent in: the design of new health care systems in hospitals, nursing homes, and home care; the next generation air traffic management system for the national airspace; considerations of unmanned aircraft systems (*e.g.*, drones) in air traffic airspace; the design of intelligent highway systems, national intelligence networks and anti-cyber threat and anti-terrorist systems; and, the design of future military systems (especially the design of new naval vessels that envision utilizing crews one-third the size of those on former naval ships). The more human factors practitioners can highlight the importance of our work in assisting system designers to overcome obstacles (and help them anticipate and implement solutions to envisioned human-operator problems), the better our profession will become, and the more seriously and effectively our inputs will be adopted in the future.

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<sup>1</sup> See the Division 21 web site at <http://www.apadivisions.org/division-21/index.aspx>.

<sup>2</sup> See also [www.hfes.org](http://www.hfes.org).

<sup>3</sup> See [www.ergonomics.org.uk](http://www.ergonomics.org.uk).

<sup>4</sup> For recent examples from the U.S. Army, see Savage-Knepshield, Martin, Lockett and Allender (2012).

<sup>5</sup> See <http://www.manprint.army.mil/>.

<sup>6</sup> See [www.nationalacademies.org/bohsi](http://www.nationalacademies.org/bohsi).

<sup>7</sup> Concurrent acquisition and test and evaluation processes emphasizing interaction among developer, tester and user communities.

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### Bio

**Gerald P. Krueger** is a Fellow in the American Psychological Association (APA) and the Human Factors and Ergonomics Society (HFES), and an Associate Fellow in the Aerospace Medical Association. He is the delegate representing the Potomac Chapter of HFES to the Washington Academy of Sciences (WAS). To showcase the myriad ways human factors specialists conduct their work, he organized and chaired four Potomac Chapter HFES mini-symposia at the WAS Capital Science events in 2006, 2008, 2010, and 2012. A retired Army officer, Dr. Krueger is a research psychologist and certified professional ergonomist. In his 45+ year career, he completed dozens of human factors engineering assessments of developmental materiel systems, in both the military and civilian sectors.



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# **Commercial Truck Driver Performance in Emergency Maneuvers and Extreme Roadway Conditions Presented in a Driving Simulator**

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Alejandra Medina-Flinstch and Richard J. Hanowski**

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## **Abstract**

There is a continual demand for qualified commercial motor vehicle (CMV) drivers in the United States. However, current standards do not provide requirements for CMV drivers, and proposed rules addressing minimum training requirements only address entry-level (novice) driver training. The purpose of this study is to examine the use of a full-mission CMV driving simulator to present scenarios relevant to defensive driver training for experienced CMV drivers, including emergency maneuvers and extreme roadway conditions, and the associated driver responses to those scenarios. A total of 48 participants across three trailer types (van-, double-, and tanker-trailers) and experience levels served as participants and completed simulated driving – including 12 emergency maneuvers and 10 extreme roadway conditions – and received a rating as to their performance on the task. Results indicated that the majority of participants across all trailer types and experience levels typically responded appropriately to the scenarios. However, approximately 30% of experienced drivers did not respond appropriately in the scenarios. The results suggest that a CMV driving simulator can be an appropriate refresher or defensive driving training tool for experienced drivers, and that further research examining experienced driver training is warranted.

## **Introduction**

**HISTORICALLY, TO OBTAIN A COMMERCIAL DRIVER LICENSE (CDL)** in the United States, individuals only had to pass a written test followed by a vehicle safety equipment inspection test, and skill tests in both a closed area and on-the-road while driving a commercial vehicle (truck, bus or motorcoach). There have been no requirements for entry-level operators to have either classroom or supervised driving time prior to licensure, nor any requirements for refresher driver training post-licensure. While proposed Department of Transportation regulations (72FR 73225, published December 26, 2007) address the void in entry-level driver training, at the time of the present study data collection (*circa* 2008-2009), no such training requirements were in place. Further, the proposed regulations do not address the issue of refresher driver training.

This lack of a standard for training commercial vehicle (CMV) drivers also affected cargo and freight carriers. In the decade leading up to the year 2008, finding and retaining qualified CDL holders was a very competitive process. Demographic trends predicted a reduction of qualified CDL holders due to driver aging and retirement. Thus, the commercial trucking industry was becoming more concerned with driver retention and the overall supply of qualified drivers (Howard, Zuckerman, Strah, and McNally, 2009). This has led to increased industry attention on the issue of refresher driver training for experienced CDL holders. Refresher training is provided post-licensure, typically on a regularly scheduled basis by the driver's employing carrier. Refresher training programs have been associated with a decrease in crash involvement (FMCSA, 1997; Morgan, Tidwell, Medina, Blanco, Hickman, and Hanowski, 2011).

Increased and standardized truck driver training programs, including providing more simulation-based driver training, was viewed as one potential method to address these concerns (Dugan, 2008). Truck driving simulators offer certain advantages, albeit with certain disadvantages, to traditional methods of driver training. Robin *et al.* (2005) identified a number of the potential benefits for training using a commercial truck driving simulator, including increased safety during training, the ability to use replicable driving maneuvers, and the ability to expose drivers to rarely occurring events and environments. In addition, simulators offer the opportunity to obtain high quality driver performance measures that can be costly to obtain from a real vehicle.

However, not all drivers are able to comfortably operate driving simulators. This discomfort with driving simulators manifests in the form of visual effects, disorientation, and nausea that has been termed "simulator sickness" (Pausch, Crea and Conway, 1992). An additional problem with the use of driving simulators is that driver performance in the simulated environment is often poorer than that observed in a real vehicle environment, leading to the possibility of artificially-lowered test scores (Morgan, Tidwell, Medina and Blanco, 2011).

The purpose of the present study was to explore the capabilities of a CMV driving simulator to provide appropriate simulations of driving circumstances requiring emergency maneuvers and extreme roadway conditions, across drivers with different experience levels and vehicle configurations (*i.e.*, van-, tanker-, and doubles-trailers). These driving circumstances necessitate a rapid response on the part of the driver and



can demonstrate the ability of the simulator to provide advanced, refresher, driver training.

Method

Participants

A total of 48 CMV drivers served as participants in this study. This number of participants represents the total number included in the analysis and excludes any participants ( $n = 12$ ) dropped due to discomfort while operating the driving simulator. They were recruited based on their driving experience levels and primary trailer type operations. Driving experience was classified into two levels: million miler drivers (*i.e.*, drivers who have logged one million consecutive miles of CMV driving without a Department of Transportation [DOT] reportable incident) and non-million milers (*i.e.*, drivers who have not reached one million consecutive miles of CMV driving without a DOT reportable incident, or who have at least one million miles, but have a DOT reportable incident on their record). Only 1 female served as a participant in this study (a van trailer non-million miler). Participant demographics are summarized in Table 1.

Table 1. Participant Demographics

| Trailer Type    | <i>n</i> | Experience        | Mean Age (Years) | Mean Experience (Years) | Mean Miles Logged Before Participating |
|-----------------|----------|-------------------|------------------|-------------------------|--|
| Van             | 6        | Million Miler     | 51               | 31                      | 2,943,000                              |
| Van             | 10       | Non-Million Miler | 44               | 8                       | 439,000                                |
| Double Trailers | 6        | Million Miler     | 51               | 23                      | 2,282,000                              |
| Double Trailers | 10       | Non-Million Miler | 42               | 12                      | 538,000                                |
| Tanker          | 6        | Million Miler     | 51               | 30                      | 2,539,000                              |
| Tanker          | 10       | Non-Million Miler | 42               | 10                      | 402,000                                |

Note: Figures rounded to the nearest integer.

### ***CMV Driving Simulator***

The driving simulator used for this study was a FAAC model TT-2000-V7 truck driving simulator. The driving simulator presents 5 forward visual channels allowing for approximately 225° forward field of view. In addition to the forward visual channels, two rear channels are provided using plasma displays mounted on the rear of the cab. These rear channels are reflected through real flat (*i.e.*, non-planar) mirrors, allowing for mirror parallax of the view alongside the trailer. The truck simulator has real working gauges, shifter (configured as a 10-speed non-synchronized manual transmission for the purposes of this study), pedals, indicators and warning lights, force feedback steering, and a 3 degree of freedom (heave, pitch, and roll) motion seat. Figure 1 provides three different views of the simulator.

### ***Maneuvers and Conditions***

A total of 12 driving circumstances necessitating emergency maneuvers, and 10 extreme driving conditions were identified for examination in this study. Driving circumstances necessitating emergency maneuvers were presented as situations requiring a driver response and were generally classified as mechanical failures, traffic, and/or changing road conditions. Extreme driving conditions were presented as either weather-related conditions or road hazards. Figure 2 provides an example of a snow-covered roadway. Descriptions of each of the scenarios examined in the study are presented in Table 2.

### ***Measures***

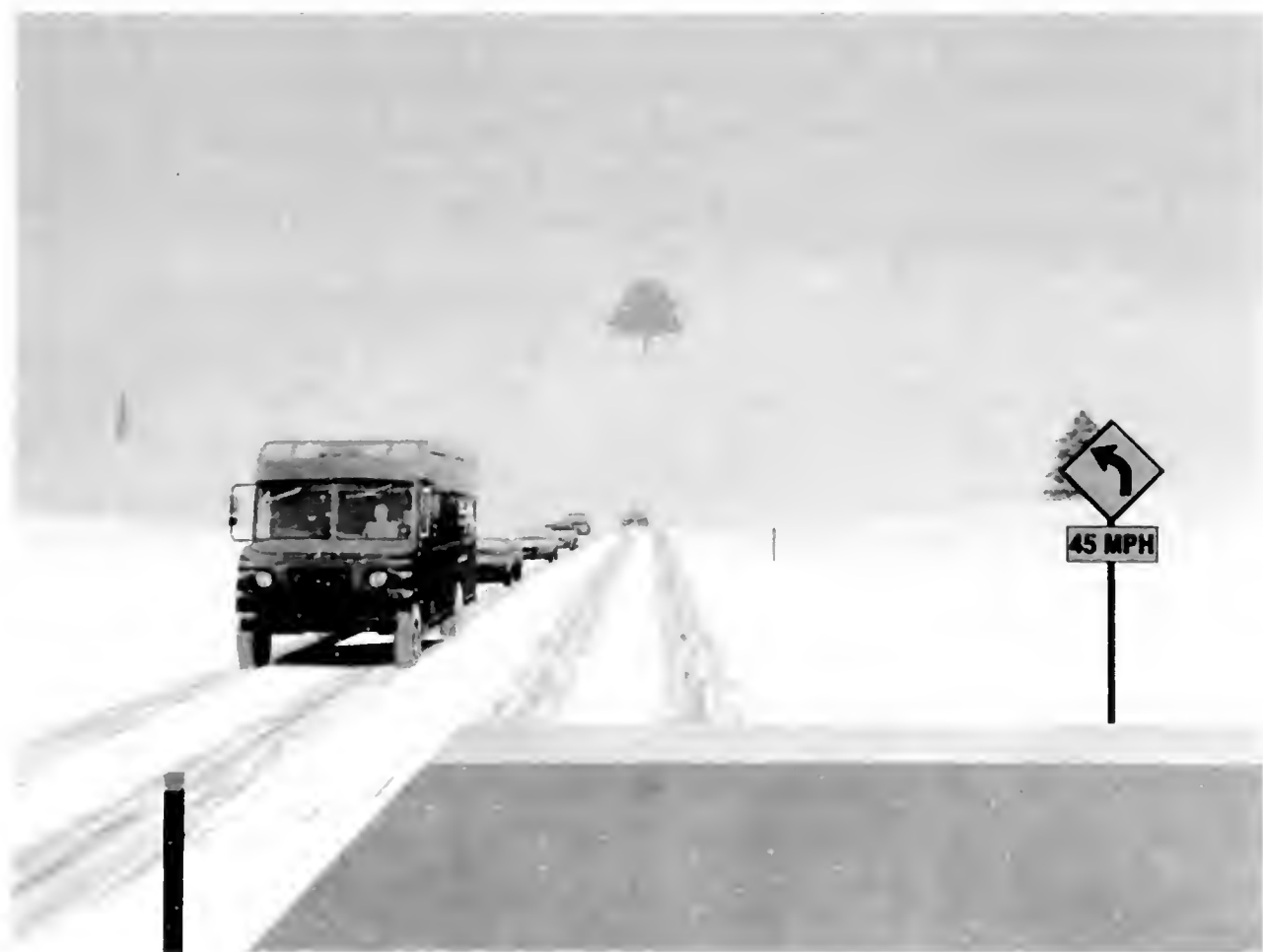
Both driving performance and subjective measures of levels of discomfort (*i.e.*, simulator sickness symptoms) were obtained. An experimenter/observer scored the driver participant's response to each emergency maneuver and extreme driving condition. Each driving response was classified as "responded appropriately," "responded inappropriately," or "failed to respond," depending on the driver's response to the situation. Responded appropriately is operationally defined as correct actions (*e.g.*, reduce speed in fog) performed to prevent or reduce severity of a safety critical event. Responded inappropriately is defined as failing to perform correct actions (*e.g.*, does not reduce speed in construction zone) to prevent or reduce severity of a safety critical event, however the driver avoids a safety critical event. In other words, the driver had a near miss. Failed to respond is defined as failing to perform correct

actions and having a safety critical event. The ratings for all 48 drivers were assigned by the same experimenter/observer.

A modified version of the Simulator Sickness Questionnaire (SSQ; Kennedy *et al.*, 1996) was used to assess participants' subjective ratings of discomfort from simulator exposure. This measure consisted of 17 symptoms that participants rated on a scale from "0" (not experiencing the symptom) to "3" (experiencing severe levels of the symptom). Symptoms in the SSQ include general discomfort, fatigue, headache, salivation, sweating, and nausea.



**Figure 1.** Three views of the FAAC TT-2000-V7 truck simulator.



**Figure 2.** Example of a simulated snow-covered roadway

Table 2. Descriptions of the Study Scenarios

| Condition  | Description  |
|--|--|
| <b>Driving Circumstances Necessitating Emergency Maneuvers</b> |  |
| Merge Squeeze  | Vehicles merging from highway entrance ramp without yielding   |
| Lane Cross   | Oncoming vehicle crossing the center line  |
| Tire Blowout   | Driver will experience a steering axle tire blowout  |
| Rollovers – Right  | Designated right hand curves that will cause a rollover event unless speed is reduced below posted warning         |
| Rollovers – Left   | Designated left hand curves that will cause a rollover event unless speed is reduced below posted warning          |
| Brake Loss   | Slow air pressure loss until brakes lock; warning light will activate at 60 lbs of air pressure                    |
| Evasive Maneuver   | Vehicle abruptly stops in travel lane on highway forcing driver to swerve into left lane or onto shoulder to avoid |
| Animal Crossing  | Driver will encounter deer crossing while traveling on a rural road  |
| Blind Entrance   | Vehicle pulls out from a blind entrance  |
| Pedestrian   | Driver will encounter a child chasing a ball out into the road   |
| Tight City Turns   | Turns causing the trailer to off-track into oncoming lane; traffic is present                                      |
| Roadway Obstruction  | Driver will encounter a deer carcass in the travel lane  |
| <b>Extreme Roadway Conditions</b>                              |  |
| Fog  | Heavy fog while driving on the highway   |
| Rain   | Heavy rain with slick roads while driving on the highway   |
| Snow   | Snow-covered roads   |
| Black Ice  | Black ice encountered on highway and exit ramp   |
| 8% Upgrade   | Continuous 2-mile grade in snow  |
| 8% Downgrade   | Continuous 2-mile grade in dry conditions  |
| 8% Downgrade (snow)  | Continuous 2-mile grade in snow  |
| Dirt Road  | Half mile in length with bumps   |
| Construction Zone  | “Construction Ahead” signs followed by left lane closure on the highway and reduced speed                          |
| Railroad Crossing  | Encountered when entering the town; signs and road marking, no crossing gates                                      |

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## *Procedure*

After the informed consent process, participants received an orientation of the simulator that included information on the various controls and adjustments of simulator driving controls. Following this, two familiarization/orientation drives were completed, followed by assessment of the driver's susceptibility to simulator sickness symptoms using the modified SSQ. This SSQ was administered twice; once after each of the familiarization/orientation drives. Participants who reported or showed visible signs of discomfort based on the modified SSQ were disqualified from participation.

After completing the simulator orientation routes, participants began the study scenario, which was constructed as a single continuous drive of approximately 75 minutes duration. The simulator was configured as a conventional truck with 10-speed non-synchronized (double clutching) manual transmission in conjunction with either a van, tanker, or a doubles trailer unit. The trailer type selected was dependent on the kind of trailer the participant currently pulled at his/her place of employment. The trailer load was selected depending on the trailer type. For those drivers pulling the 53-foot dry van trailer of the set of double trailers the load was set as an evenly distributed full load (*i.e.*, 80,000 lbs. gross vehicle weight rating) while the those drivers pulling the tanker trailer experienced a half-load configuration to assess the more hazardous condition of the slosh and surge effects.

The experimenter/observer provided verbal driving directions while scoring the participant's performance. The experimenter only announced instructions on which roads to take and did not cue the driver to any pending events. The participant experienced different emergency situations and extreme conditions along the 75-minute drive. In the event of an incident or crash, the experimenter used a remote control that allowed the scenario to be restarted at the point 30.0 s before the incident or crash occurred. This allowed the driver to continue driving progress from the point before the incident, however without repeating the incident or collision. At the completion of the scenario, the participant stopped and parked the simulated vehicle and exited the simulator. The participant then completed a questionnaire about the simulated drive. This allowed the participant to rate the realism of each of the emergency maneuvers and extreme driving conditions on a five-point scale. (For a discussion of these results, see Morgan, Tidwell, Medina, Blanco, Hickman, and Hanowski, 2011).

Due to the complexity of the simulation and the variability of human responses, there were some instances where the participant failed to experience the event. Drivers were instructed to drive the simulator as they would normally drive in their real trucks. This was necessary as to not bias drivers of upcoming events. However, this more natural approach to driver instruction could lead to a missed event. For example, a driver could move into the left lane well in advance of an interchange, thus negating the merge squeeze event. Participants were not asked to perform the maneuver(s) again and these instances were treated as missing data. These instances represent less than 2% of emergency maneuvers and less than 1% of extreme conditions across all participants.

Results

*Driving Circumstances Necessitating Emergency Maneuvers*

Data for this analysis consisted of the categorical rating of driver participant responses to each of the emergency maneuvers as assigned by the experimenter. As depicted in Table 3, the majority of participants across all experience levels and vehicle types responded with appropriate driving performance to the emergency maneuvers. The lowest percentage of appropriate responses was seen in the tanker trailer, non-million miler participants, who responded appropriately to 57.3% of events. In contrast, the highest percentage of appropriate responses was observed in the van trailer, million miler participants, who responded appropriately in 80% of events.

**Table 3.** Overall Responses to Emergency Maneuvers

| Group             | Vehicle Type    | Response    |               |                           |
|-------------------|-----------------|-------------|---------------|---------------------------|
|                   |                 | Appropriate | Inappropriate | No Response/<br>Collision |
| Million Miler     | Van Trailer     | 80%         | 14%           | 6%                        |
| Non-Million Miler | Van Trailer     | 67%         | 27%           | 6%                        |
| Million Miler     | Tanker Trailer  | 65%         | 32%           | 3%                        |
| Non-Million Miler | Tanker Trailer  | 57%         | 33%           | 9%                        |
| Million Miler     | Doubles Trailer | 71%         | 20%           | 9%                        |
| Non-Million Miler | Doubles Trailer | 61%         | 27%           | 12%                       |

Note: Figures rounded to the nearest integer.

Comparisons between the responses, based on ratings assigned by the experimenter of million miler and non-million miler participants, were evaluated for the emergency maneuvers using Fisher’s exact tests. Evaluation of the 12 emergency maneuvers indicated a significant difference between tanker trailer million milers and non-million milers for the off-road recovery scenario ( $p = 0.035$ ). This finding suggests that tanker trailer million milers were more likely to respond appropriately than non-million milers for this scenario. Likewise, a significant difference was found between van trailer million milers and non-million milers for the tire blowout event ( $p = 0.035$ ), suggesting that van trailer million milers were more likely to respond appropriately than van trailer non-million milers for this scenario. No other comparison of experience levels in the emergency maneuvers reached statistical significance.

*Extreme Roadway Conditions*

Results for the analysis of the extreme condition responses yielded similar results to those of the emergency maneuver responses. The majority of all participant groups responded appropriately to the extreme condition scenarios. The lowest percentage of appropriate responses was observed in van trailer, non-million miler participants, at 54.6%, while the highest percentage of appropriate responses was observed in tanker trailer, million miler participants, at 73.3%. Overall responses are provided in Table 4, below.

**Table 4.** Overall Responses to Extreme Conditions

| Group             | Vehicle Type    | Response    |               |                           |
|-------------------|-----------------|-------------|---------------|---------------------------|
|                   |                 | Appropriate | Inappropriate | No Response/<br>Collision |
| Million Miler     | Van Trailer     | 63%         | 35%           | 2%                        |
| Non-Million Miler | Van Trailer     | 55%         | 41%           | 4%                        |
| Million Miler     | Tanker Trailer  | 73%         | 27%           | 0%                        |
| Non-Million Miler | Tanker Trailer  | 60%         | 37%           | 3%                        |
| Million Miler     | Doubles Trailer | 67%         | 30%           | 3%                        |
| Non-Million Miler | Doubles Trailer | 70%         | 29%           | 1%                        |

Note: Figures rounded to the nearest integer.

Comparisons between the responses for the two experience levels were examined using Fisher's exact tests. The 10 extreme conditions were examined for differences between experience levels for each vehicle operation type. Results indicated a significant difference between doubles trailer million milers and non-million milers during the black ice extreme condition ( $p = 0.036$ ); doubles trailer non-million milers were more likely than doubles trailer million miler doubles participants to respond appropriately. No other comparison of experience levels in the extreme conditions reached statistical significance.

## **Discussion and Conclusion**

### ***Study Findings***

No overall pattern of major statistical differences was found when comparing drivers of different experience levels across different operation types. The overall performance during the 12 emergency maneuvers and 10 extreme conditions illustrates that the majority of driver participants demonstrated appropriate responses to the simulated scenarios. Also, while not a statistically significant difference, million milers responded appropriately to both emergency maneuvers and extreme conditions more frequently than did non-million milers. However, it should be noted that the million miler participants still responded inappropriately (or not at all) in approximately 30% of the emergency events and 32% of the extreme conditions encountered. There are multiple potential explanations for this finding. The results suggest that all participants, including million milers, could potentially benefit from refresher defensive driver training that could be offered in truck driving simulators such as used in this study. The use of a CMV driving simulator with appropriately experienced driver trainers could be an appropriate mechanism for this type of training. Indeed, a full-mission CMV driving simulator, when used by a trainee as part of a certified CMV driver training program, has been shown to result in equivalent levels of skill performance (Morgan, Tidwell, Medina, and Blanco, 2011). More research is certainly called for in regards to the use of CMV driving simulators for refresher defensive driver training.

An alternative explanation is that the simulator may not capture the full nature of the driving task, leading to a performance decrement between simulator and real-world driving. This effect has been noted in comparisons of simulator and real-world driving (Morgan, Tidwell, Medina, and Blanco, 2011). Unfortunately, the differences between simulator and real-world driving are poorly understood. A myriad of



factors, such as the type of simulator, the scenario being used, and individual differences, may have an effect on the results of a simulator study. Formal research investigating the differences in performance between simulator and real-world driving is needed.

### ***Future Steps in Commercial Motor Vehicle Driver Training***

The proposed DOT regulations (72FR 73225, published December 26, 2007) address entry-level CMV driver training and set minimum standards for the number of classroom hours (76 hours addressing issues such as basic operation, safe operating practices, vehicle maintenance for a Class-A CDL) and behind-the-wheel hours (44 hours addressing basic operation, safe operating practices, and advanced operating practices with a trainer supervising and providing feedback for a Class-A CDL) needed prior to testing to obtain a CDL. However, there are no current or proposed regulations for refresher or defensive driver training for CMV operators. It is common for drivers to be unaccustomed with certain driving conditions (*e.g.*, steep mountain grades, heavy snow, *etc.*) as freight and commodities may require transport many miles from their origin through different terrain and climates.

Additionally, commercial truck drivers may become habituated to certain skills and tasks and develop inappropriate driving behaviors. Although many truck carriers recognize this need for refresher and defensive driver training, there are no guidelines for the design and implementation of this type of training. The implementation of both refresher and defensive driver training vary widely and can range from no additional training provided, to additional training only after a safety incident has occurred, or a yearly refresher/defensive driver training requirement. As the results of this study highlighted, even million miler drivers still responded inappropriately or not at all in approximately 30% of the conditions. This suggests that these drivers, and in fact all drivers, may benefit from additional training post-licensure.

A full-mission truck simulator, similar to the one used in this project, can provide a valid tool for the implementation of either a refresher or defensive driver training program. The use of a simulator can provide for repeated training exposure of driving events and conditions for the individual driver and between drivers to improve the transfer-of-training, training efficiency, and safety of the training process. This allows for situational training that would be impractical or unsafe to perform in a real vehicle. The development of refresher training scenarios and topics,

methodology, and implementation can be applied across all simulator platforms and throughout the trucking industry to create a standardized approach to this type of training.

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# Springs of Washington, D.C.: A Tale of Urbanization

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## Abstract

Washington, D.C., once utilized springs and shallow wells as its principal water resources, but as these sources became contaminated, the city switched to treated surface waters. The small streams and most springs were buried by subsequent construction or covered intentionally for health reasons. With the water table now well below the land surface, spring flows ceased. Some streams were converted to storm sewers, and few spring locations were preserved. In some cases, their sites can be inferred from historical records, subtle topographic indications, or from building features indicating past topographic lows. However, the shallow hydrogeological system still operates under the city's veneer of roads, parking lots, parks, and buildings. In addition, swamps, tidal marshes, and wetlands have been filled-in to provide land for construction, roadways, and parks. This buried geology and hydrology should be considered in the development of Washington, D.C., and any city.

## Introduction

**IN 1629, CAPTAIN JOHN SMITH** described the future site of Washington, D.C., as a “country is not mountainous, nor yet low, but such pleasant plaine hills, and fertile valleys, one prettily crossing another, and watered so conveniently with fresh brooks and springs, no lesse commodious, then delightsome” (Smith, 1629). Until 150 years ago, springs and shallow-dug wells were the main source of drinking water to residents of Washington, D.C. Now Washington has the many amenities and all the advantages and disadvantages of a modern city. Its shallow geology and hydrology have been drastically altered by more than two centuries of development. In 2012, the Geological Society of Washington sponsored a field trip (Sharp, 2012) that examined sites of the “fresh brooks and springs” that originally made this area attractive for settlement. This paper is based upon that field trip, which was, in turn, generally based upon Williams (1977), who, in celebration of the nation's bicentennial, examined changes in water supply and water courses since 1776. He examined old newspaper files to determine the location of the city's springs.

Mankind is now one of the major agents affecting the Earth's biology, geology, and hydrology. Washington, D.C., is not unique in demonstrating how mankind and, especially, urbanization changes our

environment. With global population pushing towards 9 billion and with the majority living in cities, we need to assess how the urban systems evolve and how we can best utilize ecosystem resources. Below, a brief discussion of the general effects of urbanization is followed by a review of the loss of streams and springs in other cities. This is followed by a focus on Washington's lost streams and springs, in particular.

### **General Effects of Urbanization**

Urbanization is one of the major geomorphic, hydrologic, and geological processes shaping the Earth (Sherlock, 1922; Chilton, 1997; Underwood, 2001; Brabec, 2009; Hibbs and Sharp, 2012). The general effects of urbanization include a number of factors discussed in this section.

**Leveling the land surface for buildings, roads, parking lots, etc.:** This includes filling low areas, such as stream channels, tidal marshes, swamps, and wetlands (Sherlock, 1922; Williams, 1977; Sharp, 2010, 2012). In the past, small streams may have been covered for reasons of the public health, whereas today we seek to remediate them. Commonly, many of the older cities of the world are built on top of their predecessors.

**Introducing new sources of air, surface-water, and groundwater contamination** (Chilton, 1997; Hibbs and Sharp, 2012; Kelly *et al.*, 2012; Wong *et al.*, 2012): Leaky underground storage tanks, abandoned factories, abandoned dumps, broken or leaky sewer lines or other pipelines, illegal waste disposal, vehicular exhaust, power plant emissions, and accidental spills have occurred and will continue to occur. The buried alluvial channels and subsurface utility systems provide permeable pathways that significantly transport contaminants and efforts for remediation.

**Altering the local (and perhaps regional) climate including the urban "heat island effect" and changes in patterns of precipitation** (Taylor and Stefan, 2009; Bhaskar and Welty, 2012): Cities are hotter than the surrounding rural lands because of the thermal effects of buildings and pavements. In some cases (*e.g.*, Chicago described by Changnon, 1976), this has been observed to increase thunderstorms in the prevailing downwind direction.

**Installing a network or reticulation of subsurface conduits, tunnels, and utility lines** (Sharp *et al.*, 2003; Sharp, 2010): This creates:

- zones of enhanced permeability, often by many orders of magnitude;
- a highly anisotropic and heterogeneous permeability field; and
- enhanced shallow secondary porosity and water storage (essentially an epikarst).

This makes it difficult to predict the direction of contaminant transport and makes remediation equally difficult or perhaps impossible. These high permeability paths can alter local natural flow systems and pirate spring flows or produce new areas of groundwater discharge. The network can also serve to control the water table elevation or, when the water and sewage lines leak, provide enhanced groundwater recharge.

**Landscaping roadways, sidewalks, parking areas, and roofs** (Moglen, 2009): These areas are commonly termed “impervious cover.” However, secondary permeability can be significant so that groundwater recharge is enhanced (Wiles and Sharp, 2008). In addition, we do not prefer to drive through water; therefore parking lots and roads have storm drains. These are internal drainage systems that flow through conduits to urban streams (essentially a karst landscape).

**Compacting natural soils** (Pitt *et al.*, 2002): Vehicular and foot traffic and construction consolidate natural soils that, in turn, often lowers permeability.

**Altering natural vegetation:** This includes introducing non-native vegetation; irrigating lawns, gardens, and parks; that affect evapotranspiration, recharge, and stream flow (Passarello *et al.*, 2012).

**Increasing groundwater recharge** (Garcia-Fresca and Sharp, 2005; Hibbs and Sharp, 2012): It is commonly assumed that pavements and impervious cover reduce groundwater recharge but the overwatering of lawns, gardens, and parks combined with leaky water, sewage, and storm drainage systems and planned artificial recharge systems (*e.g.*, storm water detention ponds, soakways, drain fields, *etc.*), generally increase groundwater recharge in cities above pre-urban conditions.

**Causing more intense urban flooding (Leopold, 1968), but perhaps maintaining low flows:** For a given rain event, floods come more quickly and have higher discharge than under pre-urban conditions because of runoff from “impervious” cover and storm drains. On the other hand, the sources of enhanced groundwater recharge listed above may keep streams flowing in times of low rainfall. In fact, in some situations, all streamflow may originally have been sourced from the city water systems (Passarello *et al.*, 2012; Snatic *et al.*, 2012).

**Lowering water tables:** This is due to the utility systems and pumping systems needed to keep building foundations, basements, underground parking garages, and metro lines dry.

**Causing springs and streams to disappear** (Barton, 1962; Williams, 1977; Brick, 2009): This is the focus of this study. See Robert Frost's poem about a brook in a city in Appendix 1.

### **Disappearing Springs and Streams**

The phenomenon of lost springs and streams is not unique to Washington, D.C. In *The Lost Rivers of London*, Barton (1962) relates how streams (many of which are featured in literature and poetry, including the Fleet River, now Fleet Street) no longer exist. Brick (2009) discusses canoeing in tunnels under St. Paul, Minnesota, which were once surface streams. The Tank Stream in Sydney, Australia, the source of drinking water for the early colonists, is now completely covered and has been converted into a storm sewer (Merrick, 1998). Tours are given twice yearly and there have been discussions on how to make this historic stream a tourist attraction. In downtown Austin, Texas, Little Shoal Creek is completely covered, and its presence only inferable by shallow dips in street topography following the old maps. In the United States, Sanborn's 19<sup>th</sup> century insurance maps are excellent reference sources for lost streams.

Generally in past centuries, small streams became polluted by sanitary practices that accompanied the growth of cities. The streams were then covered over as a public health measure. Nevertheless, the alluvial sediments of high permeability still exist and, as pointed out by O'Connor *et al.* (1999), they still effectively transport water -- and occasionally contaminants. Additionally, periods when the water table becomes high, geotechnical problems and flooding by groundwater also occur.

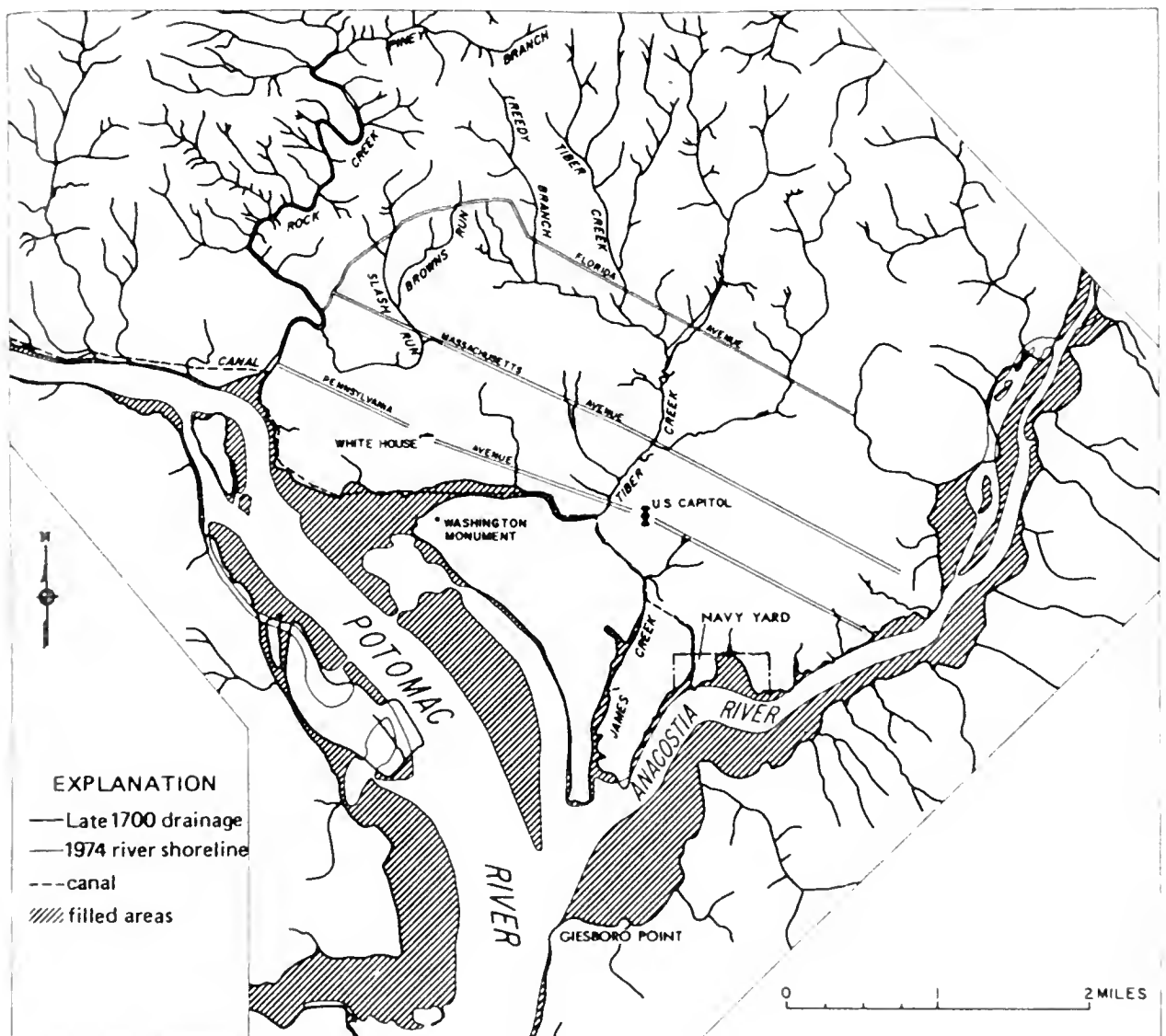
### **Streams of Old Washington**

Maps in Millay (2005) and Williams (1977, reproduced as Figure 1 below) show the major streams and filled-in low-lying areas as they existed in the late 18<sup>th</sup> century. There were over 80 streams in the city. In the 1870s, the city buried the last of its creeks, with exception of Rock Creek, which was saved by the decision to make it into a park. Prominent buried streams included Tiber Creek, James Creek, Piney Branch, and Slash Run, but these and others may still exist in some form, subsurface (O'Connor *et al.*, 1999; Millay, 2005). These were not all inconsequential streams; Tiber Creek, for instance, which once flowed under the present



Museum of Natural History, was a significant source of shad roe. The alluvial sediments are still there. These alluvial channels still control groundwater flow patterns and should be considered in planning for storm drainage or remediation of groundwater contamination.

Swamps, tidal marshes, and wetlands have been filled in partly because of real or perceived health hazards, but more significantly to provide solid land for new construction. Extensive areas along the Potomac and Anacostia Rivers were reclaimed (see Figures 1 and 2). Many roadways, parts of the National Mall, the Tidal Basin, and the Jefferson Memorial are on filled lands. The recent repairs at the Jefferson Memorial attest to some of the geotechnical issues that have since arisen. O'Connor *et al.* (1999) also documented 11 smaller wetlands that were covered over in the 19<sup>th</sup> century (see Table 1).



**Figure 1.** Williams' (1977) map of Washington, D.C., streams in the late 18<sup>th</sup> century. Only Rock Creek still exists as a stream. Also shown are areas that were filled in by 1974, and the canal running from Georgetown to south of the White House and southwest of the Capitol, and then to the Anacostia River by the Navy Yard.



**Figure 2.** The Capitol as seen from the marsh, Anacostia River. Photo by John K. Hillers, n.d. (1880s).

### **Springs of Old Washington and the Springs Today**

Williams also listed 38 springs of old Washington, D.C., and their locations. These and their present situations are listed in Appendix 2. Many of these were obtained from old newspaper accounts. Access to all the sites was possible during my field reconnaissance in 2010 except for those in areas currently under military jurisdiction (i.e., Smith Springs at the McMillan Reservoir; Dunlop Spring at the U.S. Soldiers Home; and the springs flowing into the Anacostia River at the Navy Yard). Only a few springs still flow into Rock Creek, most are now well below the land surface. The locations of some can be inferred from the recorded details of their location, by topographic subtleties, and -- because they flowed into creeks and ravines (topographic lows) -- building construction may indicate these lows. Springs were the chief source of drinking water until the Civil War, when river water began to be utilized. In the early 20<sup>th</sup> century, a city water system replaced all the springs and shallow wells as the drinking water source. Below are pictures showing the actual or inferred sites of four of Washington D.C.'s springs listed by Williams: Caffrey's, Franklin Square, Capitol Hill, and Quarry Road Springs. Sharp (2012) includes photos of most of the other spring sites listed by Williams. There were other springs in and around the District, including Silver Spring (Maryland), also shown below, and in the National Arboretum.

Finally, there were many other now extinct springs not listed by Williams, such as along today’s Spring Road leading into Piney Creek Park.

**Table 1.** 19<sup>th</sup>Century Buried Wetlands (provided courtesy of Will Logan and the late Jim O’Connor)

| Wetland (Type)                                | Watershed Location                       |  |
|---|--|--|
| Alder Swamp                                   | Tiber Creek                              | Botanical Gardens reflecting pool            |
| Murder Bay Marshes (tidal freshwater)         | Tiber Creek                              | Reagan Building to Museum of Natural History |
| Hamburg Marshes (wild rice)                   | Tiber Bay                                | Lincoln and Vietnam Memorials                |
| Anacostia Flats (arrow arum beds)             | Anacostia Estuary                        | Old mouth region on both sides               |
| Benning Marsh (Carolina rail hunting)         | Anacostia Estuary                        | RFK Stadium                                  |
| W.B. Shaw Lily Ponds                          | Anacostia Estuary                        | Kenilworth Aquatic Gardens                   |
| Magnolia Run Bogs                             | Piney Branch at Magnolia Run             | Ingraham and 5 <sup>th</sup> St., NW         |
| Holmead Swamp (magnolia swamp)                | Piney Branch at Spring Run               | Spring Road and Holmead Place                |
| Mayflower-Walker Swamp (bald cypress swamp)   | Slash Run                                | Mayflower Hotel National Geographic          |
| Lafayette Park/Terrace Swamp (tundra pollen)  | Duck Creek Slash Run                     | Lafayette Park                               |
| Terrace Escarpment (floodplain swamp – reeds) | Reedy Branch at Tiber Creek West         | Florida Avenue, NW                           |
| Swampdoodle (village for poor immigrants)     | Confluence of East and West Tiber Creeks | Gonzaga High School                          |

Caffrey’s Spring (Figure 3) was also called Hotel, Burnes, St. Patrick’s, and Federal Spring. The lowest point of the intersection of 9th and F Streets NW is the northwest corner, which is the spring’s location. Franklin Square Spring (Figure 4) in Franklin Square was one of a set of springs in this general area. It was abandoned as a water supply early in the 20<sup>th</sup> century because of contamination.



**Figure 3.** Caffrey’s Spring was at the northwest corner of 9<sup>th</sup> and F Streets, NW. This is the lowest part of the intersection today. This spring was used until 1870.



**Figure 4.** Franklin Square Spring in an originally marshy ground with a number of springs that provided water to the White House and the Departments of State, War, Navy, and Treasury from 1832 to 1906. The orifice is inferred to have been in the lowest bricked area behind the fountain.

Some springs are more clearly identified. Capitol Hill Spring (Figure 5) is located in a brick gazebo northwest of the Capitol, and probably provided water for early congresses. The orifice is now well below ground. This spring would have flowed into Tiber Creek.



**Figure 5.** Capitol Hill Spring, northwest of the Capitol near Pennsylvania Avenue. The orifice is now well beneath the land surface. Presumably, this once served the Congress.

Figure 6 shows Quarry Road Spring, which once flowed into the east (left) bank of Rock Creek. The orifice location now hosts a storm sewer outlet. The sign in the background reads: “WARNING! Sewage. Avoid contact with water after rain.”

Silver Spring (Figure 7), Maryland, is another prime example of how urbanization affects springs. The orifice can be located because of the spring’s historical significance, but it is now well below (1-2 m) the ground surface. The stream to which it once flowed no longer exists. It is buried, but might be inferable from mapping land surface elevations. The spring no longer flows, but there is occasionally water present. However, it is hard to discern if this is natural spring flow or just outflow from the city water system.



**Figure 6.** Quarry Road Spring, east bank of Rock Creek, now issues from a storm sewer. In May 2010, there was discharge from the site, but how much of this was storm water or sewage flow is unknown. In May 2012, there was no flow.



**Figure 7.** Silver Spring, Maryland, was named for this spring that is on land once owned by the Blairs, prominent politicians in the Lincoln years. The spring was named for the glittering mica flakes in the sunlight where the spring bubbled out of the ground. The stream into which the spring discharged is covered. There is a grate at the bottom near the spring, and the spring doesn't flow. The spring orifice is probably still locatable only because of its historical significance.



## Conclusions

The role and effects of urbanization on small streams and springs seem universal. Leveling of the land surface and filling of low areas, including wetlands, is the general rule. Consequently small streams and springs become buried and perhaps forgotten. Most of the Washington, D.C., streams are buried and few, if any, of the springs continue to flow. Some streams have been converted to storm drains. Sump pumps and drainage systems keep water tables low even if urban recharge increases. But the sediments and flow systems still exist in the subsurface. As urban expansion continues, we should consider how springs and small streams can contribute to the urban environment and perhaps as local water resources for other uses.

## Appendix 1

### *A Brook in the City*

A poem by Robert Frost

The farmhouse lingers, though averse to square  
 With a new city street it has to wear  
 A number in. But what about the brook  
 That held the house as in an elbow-crook?  
 I ask as one who knew the brook, its strength  
 And impulse, having dipped a finger length  
 And made it leap my knuckle, having tossed  
 A flower to try its currents where they crossed.  
 The meadow grass could be cemented down  
 From growing under pavements of a town;  
 The apple trees be sent to hearthstone flame  
 Is water wood to serve a brook the same?  
 How else dispose of an immortal force  
 No longer needed? Stamped it at its source  
 With cinder loads dumped down? The brook was thrown  
 Deep in a sewer dungeon under stone  
 In fetid darkness still to live and run –  
 And all for nothing it had ever done.  
 Except forget to go in fear perhaps.  
 No one would know except for ancient maps  
 That such a brook ran water. But I wonder  
 If from its being forever under,  
 The thoughts may not have risen that so keep  
 This new-built city from both work and sleep.

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## Appendix 2

### Washington, D.C., Area Springs (Modified from Williams, 1977)

Photographs of many of these sites are included in Sharp (2012). The first 38 springs are listed by Williams, but there are and certainly were many more in the Washington, D.C., area.

1. **Smith Springs (also called Congressional or Effingham) at site of McMillan Reservoir.** Access is restricted. This is still a waterworks for DC. Three springs discharged 7, 4.5, and 3 gallons per minute (gpm), and were considered the most important of the city's springs. From 1832 to 1905, they supplied water to the Capitol and Treasury Department buildings. Access is difficult.

2. **City (Ridge), north of C Street, between 4 ½ and 6<sup>th</sup> Streets, NW.** The best guess for the spring orifice is in the low garden area south of the Courthouse. It was used from about 1802 to at least 1900.

3. **Caffrey's (also called Hotel, Burnes, St. Patrick's, Federal), northwest corner of 9<sup>th</sup> and F Streets, NW.** This is the lowest part of the intersection today. The spring was used until 1870. (Site photo is Figure 3.)

4. **City Hall, northwest corner of 5<sup>th</sup> and D Streets, NW.** The spring orifice location is inferred from the lower floor elevation and inferences about the previous topography from building construction. The ramps down to the bottom floors of the buildings suggest that they were constructed near a stream valley.

5. **Franklin Square.** This was originally low and marshy ground with a number of springs, which provided water to the White House and the Departments of State, War, Navy, and Treasury from 1832 to 1906. The orifice is inferred to have been in the low area behind the fountain. (Site photo is Figure 4.)

6. **13<sup>th</sup> and K Streets.** This spring is completely covered; no evidence of it exists. It may have been located under the old Franklin School.

7. **Gibson (also called Cool, Young, Stodderts, Federal), 15<sup>th</sup> and E Streets, NE.** This spring housed an ice house until 1959. A local resident with whom I chatted related that the ice house burned down in the late 1950s, and that the spring would have been located under the apartment complex now covering the site.



**8. Capitol Hill, northwest of the Capitol near Pennsylvania Avenue.** This pleasant brick building surrounds and is adjacent to the pit that presumably was the spring's orifice, which is now well beneath the land surface. Presumably this spring once served the Congress. (Site photo is Figure 5.)

**9. Spring Garden, south side of canal, west of 6<sup>th</sup> Street, NW.** Looking east across the Mall from the National Gallery of Art, the location -- which is still a relatively low area in this portion of the Mall -- would have been slightly to the southeast from the main entrance. It would have been adjacent to the canal shown on Figure 1. The canal lock keeper's house still stands on Constitution Avenue.

**10. Carroll, New Jersey and Virginia Avenues, SE.** This was a group of springs and it is difficult to infer their precise location, but the old canal is clearly visible here. Along the canal are manhole covers into the sewer lines that are buried along the old canal route. The D.C. Police also stable horses here.

**11. Pennsylvania Avenue and 24<sup>th</sup> Street, south of the Library of Congress.** Several springs here once gave rise to a small tributary of James Creek. The springs are completely covered and no evidence of them exists.

**12. Intersection of North Carolina Avenue, D Street, and 34<sup>th</sup> Street, SE.** This is in Folger Park. There are several disused fountains in the park that may have discharged spring waters at one time.

**13. Gales (Eckington), northeast of the intersection of 1<sup>st</sup> Street and Florida Avenue, NE.** The spring location is inferred to have been at the lowest part of the intersection.

**14. Reedbirds Hill, N. Capitol Street, and M Street.** "...[A] spring of clear and cool water that often quenched the thirst of blackberry hunters and others ..." (Williams, 1977, p. 5) There is a garden area at this location.

**15. Dunlop, just east of the U.S. Soldiers Home.** Access was restricted, but the spring is inferred to be at the pond along the creek flowing to the east on the map at the visitor center. This spring may have supplied Lincoln's drinking water during the summer, as he and his family spent time here to escape the D.C. summer heat. Access is restricted.

**16. Right bank of Anacostia River between C Streets, N. and S. Navy Yard.** Access is restricted.

17. **Post Office, northwest corner of 7<sup>th</sup> and E Streets, NW.** The orifice location is inferred from the lower floor elevation as was noted for City Hall Spring.

18. **Leech, New York Avenue between 5<sup>th</sup> and 6<sup>th</sup> Streets, NW.** An early physician kept his leeches in this spring. The spring is completely covered and no evidence of it exists, but is probably beneath the parking lot. There is a deep manhole with a grate that may be located over the stream that was fed by this spring.

19. **Blue House, on 10<sup>th</sup> Street, between K Street and Massachusetts Avenue, NW.** The orifice location is inferred from the lower floor elevation as was noted for City Hall Spring.

20. **Willow (Willow Tree), north of L Street, between 4<sup>th</sup> and 5<sup>th</sup> Streets, NW.** This spring fed a “prominent stream” that flowed into Tiber Creek and was inferred to be at the low spot in the topography. In May 2012, this site was covered over for a new condominium complex and its location cannot be inferred.

21. **Southeast of the intersection of 10<sup>th</sup> and M Streets, NW.** The spring is completely covered and no evidence of it exists.

22. **Massachusetts Avenue, between 15<sup>th</sup> and 16<sup>th</sup> Streets, NW.** The spring, which flowed into Slash Run, is inferred to be at this lowest spot in the topography underneath the grates covering the building’s utility systems. Jefferson is said to have contemplated this spring as a source of water to the White House.

23. **Southside of Rhode Island Avenue, east of Connecticut Avenue, NW.** The spring is covered, but is inferred to be at the statue.

24. **Brown’s, north of Florida Avenue, between 14<sup>th</sup> and 15<sup>th</sup> Streets, NW.** This spring produced a “sizable stream” that flowed into Slash Run. It is inferred to be at this lowest spot in the topography under the grates covering the buildings utility systems.

25. **18<sup>th</sup> Street, near Boundary Street (Florida Avenue), NW.** The spring is inferred to be at the lowest spot in the topography. As noted for City Hall Springs, some of the buildings have ramps/steps down to the first floor.

26. **13<sup>th</sup> Street, near Florida Avenue, NW.** The spring is inferred to be at the lowest point of the intersection.

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27. **Moore's, vicinity of Florida Avenue and 11<sup>th</sup> Street, NW.** This was the origin of one of the branches to Tiber Creek. The spring is completely covered and no evidence of it exists, but again is inferred to be under the grates. However, the Florida Avenue Grill is a great breakfast stop ... watching the cook work the griddle is a highlight of a Sunday morning excursion in D.C.

28. **11<sup>th</sup> Street between Florida Avenue and Euclid Street, NW, on the grounds of Cardozo High School.** The spring is completely covered, and no evidence of it exists. There is a garden on the east side of the high school, but it appears to be too high topographically for a spring location.

29. **Head of Reedy Branch, near 13<sup>th</sup> and Harvard Streets, NW.** The spring is completely covered, and no evidence of it exists.

30. **James White, near the northwest corner of 16<sup>th</sup> and Ingraham Streets, NW.** This is a nice park area, but the spring is completely covered and no evidence of it exists.

31. **Octagon House, northeast corner of 18<sup>th</sup> Street and New York Avenue, NW.** No trace of the spring exists.

32. **Easby's Point, just east of the Kennedy Center.** The spring may have been in the vicinity of the Center's underground parking garage.

33. **Virginia Avenue between 26<sup>th</sup> and 27<sup>th</sup> Streets, NW.** No trace of this spring now exists.

34. **East bank of Rock Creek near K Street, NW, near the Thompson Boat Center.** This spring provided Georgetown residents their best drinking water after the K Street Bridge was constructed in 1792. In May 2010, there was discharge from the spring site. How much of this was storm water flow is unknown. In May 2012, there was no flow. There are some interesting displays on the past and future of the herring fishery in Rock Creek.

35. **P and 22<sup>nd</sup> Streets, NW, east bank of Rock Creek.** "Reportedly a favorite spot for courting couples." (Williams, 1977, p. 4) There is a brick outflow from a storm sewer that marks the location.

36. **Quarry Road, east bank of Rock Creek.** In May 2010, there was discharge from the spring site. How much of this was storm water or sewage flow is unknown. In May 2012, there was no flow. (Site photo is Figure 6.)

37. **Pierce Mill, on Tilden Street west of Rock Creek.** The old spring house still exists. It was built in 1801 around the spring for use as a cooling place of dairy products. The streamcourse to which the spring flowed can be discerned, but there is no stream now.

38. **Corner of Wisconsin Avenue and Q Street, NW, in Georgetown.** “Waters eroded a ravine southward to the Potomac.” (Williams, 1977, p. 4) The spring is completely covered and no evidence of it or the ravine exists.

The above 38 springs were listed by Williams to which I only add two noteworthy springs –Silver Spring (#39) in Maryland and the springs at the National Arboretum (#40). Others could be added.

39. **Silver Spring, Maryland.** This D.C. suburb is the name for this spring that is on land once owned by Francis and Montgomery Blair, prominent politicians in the Lincoln years. It is located next to the acorn-shaped gazebo. Silver Spring was named because of the glittering of the mica flakes in the sunlight where the spring bubbled out of the ground. The stream to which the spring discharged is covered. There is a grate at the bottom near the spring, and the spring doesn't flow. Clearly, the spring orifice is still preserved because of its historical significance. The historical plaque reads “In 1842, Francis Blair built a country house near this park and divided his time between [this site]...and his city residence “Blair House,” which is now the President's official guest house in Washington, D.C. ...” (Site photo is Figure 7.)

40. **The springs at the National Arboretum, off Springhouse Road, just south of New York Avenue.** There are two beautiful spring houses with conical roofs at this location. The springs were used for drinking water and also washing clothes. The water levels are now below the ground surface and can be measured in the standing wells in the spring houses. There are no evident discrete points of discharge to the nearby stream (which hosted beavers in 2010).

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## Bio

**John M. (Jack) Sharp, Jr.** is the Carlton Professor of Geology at The University of Texas; he has served as president of the Geological Society of America. His research interests include the effects of urbanization on groundwater systems and the hydrogeology of fractured rock systems, karst, and sedimentary basins.





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## Outgoing President's Remarks

James Cole

The Washington Academy of Sciences has had another successful year, and I want to thank all of the members of the board and our journal editors for their continued efforts throughout the year. I also want to thank Peg Kay, former president and executive director, for her assistance during this transition year of her retirement.

One of our successes this year was instituting the availability of online board meetings for the Academy, increasing participation at our board meetings. I would estimate that typically each month four board members who may not have been able to attend in person were able to attend via the web.

We had a successful year with our programs:

Our October symposium, Pediatric Cancer in the 21st Century: Harnessing Science to Improve Outcomes, was moderated by the world-renowned director of Texas Children's Cancer Center, Dr. David Poplack.

In December we held our annual Science is Murder program which is always fun. A BBC radio reporter, Jane O'Brien, attended and interviewed Peg Kay, myself, and several of the authors. This resulted in a short announcement of our event, and discussion our new imprint of science validity – which was later broadcast to an audience of approximately 120 million listeners! It was followed up by a web post by BBC.

Tonight [May 15, 2013], for the Academy's annual meeting, we heard an excellent talk here at the American Association for the Advancement of Science by Dr. James Mercer on "Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites."

A special thank you is reserved for the Academy's board member Dick Davies who manages the activities of the Junior Academy with great success.

This year I worked closely with our incoming president Jim Egenrieder, and I expect an exceptionally smooth transition to his administration.

I would also like to thank my wife, Diane, for her support during this past year.

## **Incoming President's Remarks**

**James Egenrieder**

I'm honored to serve as President of the Washington Academy of Sciences for 2013-2014 term.

It's my hope that – with the help of my colleagues on the Board of Managers, the active engagement of our Committee leaders and volunteers, and the support of our members and affiliate societies – we will continue to advance the mission of the Academy, but also continue to refine its image for this second decade of the 21st century.

I want to promote an Academy that is agile and responsive to issues of science in our region, available for partnerships and collaborations with a broad representation of the community, and representative of its current and future membership. In particular, I want to advance and highlight the excellent outreach work of our Junior Academy in local science and engineering fairs, expos and festivals.

During the next year I hope to fully document Academy procedures and processes; identify or build technologies that make those processes the most efficacious; reduce the administrative burdens of our volunteers; and emphasize the interests, talents, and professional achievements of our members and allies.

I envision we'll be equally earnest in our efforts to: build allegiances with university partners, develop new student groups, identify interesting speakers, presentations and demonstrations, and help create media and forums for all those in the National Capital Region who strive to understand what, how, and why things are the way they are.

In less than a year, we'll again host Capital Science 2014 (CapSci14), in which we'll feature the research and explorations of our members and affiliate societies.

I hope that you will all be willing share ideas and suggestions for strategies that help the Academy overcome the challenges faced by so many other professional societies and fraternal groups not able to adapt to a modern, global, technological information-age.

Most importantly, of course, is for each of you to be on the lookout for new members, new affiliates, and certainly those worthy of recognition through our Academy's awards and Fellowship.

I hope that everyone who hears this (or perhaps reads these words in our excellent Journal publication), will consider this an invitation to get involved, re-involved, or reach out in new directions that represent the Academy well.

Thank you for your continued involvement in the Academy.



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## Journal of the Washington Academy of Sciences

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3. Papers should be 6,000 words or fewer. If there are 7 or more graphics, reduce the number of words by 500 for each graphic.
4. Include an abstract of 150-200 words.
5. Graphics must be in graytone, and easily resizable by the editors to fit the Journal's page size. Reference the graphic in the text.
6. Use endnotes, not footnotes. The bibliography may be in a style considered standard for the discipline or professional field represented by the paper.
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(continued on next page)



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(continued from previous page)

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## Journal of the Washington Academy of Sciences

**Editor**

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## Editor's Comments

Our first paper in this issue, by Samuel Biondo, introduces an “intriguing” biomonitoring buffer concept that expands on the concept of multiple buffer zones to block the transport of pollution from external sources. The concept is based on proven elements, but has not been reported or even discussed in the open literature yet. The paper offers suggestions for proof-of-concept testing in hopes it will provide motivation for conducting field trials.

The second paper by Carl Mungan and Trevor Lipscombe, “Newton’s Rotating Water Bucket,” presents a lucid explanation of the not-so-obvious subtleties underlying Newton’s classic rotating water bucket.

Third, Kelsey Gilcrease examines historical and current laws governing leporids — rabbits and hares — which are usually assumed to be abundant! Some populations in North America, however, are declining. This interesting study examined 19<sup>th</sup> century wildlife laws regarding these animals in the United States to provide a historical baseline for improving our modern-day conservation efforts on their behalf.

Our final paper of the issue, “Coiled Tubing Operations May Offer Paradigm Shift in Humanitarian Logistics” by Apoorva Sinha is a fascinating concept piece revealing how a group of young innovators are currently exploring the technical feasibility and organizational sustainability of their new business venture called “TOHL” for Tubing Operations for Humanitarian Logistics. TOHL is a start-up non-profit based on a logistical innovation that is a departure from the conventional methods of using disaster-affected roads and bridges for aid delivery. The paper presents some of the background, decision-making, and analyses that have been involved in their creative undertaking.

Lastly: In a previous issue, I acknowledged the assistance of students from the excellent Science Communication Graduate Program at George Mason University (GMU). This time around, I’d like to thank Lance Schmeidler who is affiliated with that program as both faculty and staff. His super ideas have helped our Journal make progress and contacts that are sure to offer useful contributions over time. We look forward to continuing to work with Lance and his colleagues at GMU.

Sally A. Rood, PhD, Editor

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# **A Conceptual Framework for Detecting, Monitoring, and Limiting the Transport of Pollution from Anthropogenic Sources with Biomonitoring and Biological Buffer Zones to Conserve Biological Diversity and Prevent Adverse Effects**

**Samuel J. Biondo, ScD**

**Washington Academy of Sciences Emeritus Fellow**

## **Abstract**

Biomonitoring is a well established scientific discipline and various types of buffer zones have been widely used for several decades. However, those practices have not yet been combined to create an effective biological system for detecting, monitoring, and limiting the transport of pollution from anthropogenic sources to conserve biological diversity and prevent adverse effects. This is a concept paper. It presents a multi-zone biomonitoring buffer concept to achieve the stated goals. Proof of concept testing is discussed.

## **Biomonitoring**

**BIOMONITORING HAS BEEN PRACTICED** for more than 100 years.<sup>1,2</sup> Biomonitoring can be used to detect and monitor the temporal, spatial, and cumulative effects of different pollutants in the ecosystem and determine the potential for long-term harmful effects. A very wide range of species and plant types have been studied as potential monitoring agents. Lichens, fungi, tree bark and leaves of higher plants are commonly used to detect the deposition, accumulation, and distribution of pollutants in the environment. Sensitive plants may show visible effects of pollution long before their effects can be observed on animals or materials. Plants have been used to establish field monitoring networks in Europe, Canada, and the United States. An example is the assessment of the effects of ozone and atmospheric heavy metal deposition conducted through the pan-European biomonitoring program operating according to a common protocol, viz., in the framework of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and crops (ICP-Vegetation) under the Convention on Long-Range Transboundary Air Pollution (CLRTAP).<sup>3</sup>

Biomonitoring has many advantages but it requires sophisticated applications. The use of indicator plants may obviate the necessity of

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expensive equipment but applications require tailored analytical plant studies compared to using commercially available physico-chemical monitoring instruments that are applied routinely in a cookbook fashion. In practice, these different methods need not be mutually exclusive, particularly for applications in urban environments. Significant synergistic benefits can accrue from combining biomonitoring with instrumentation.

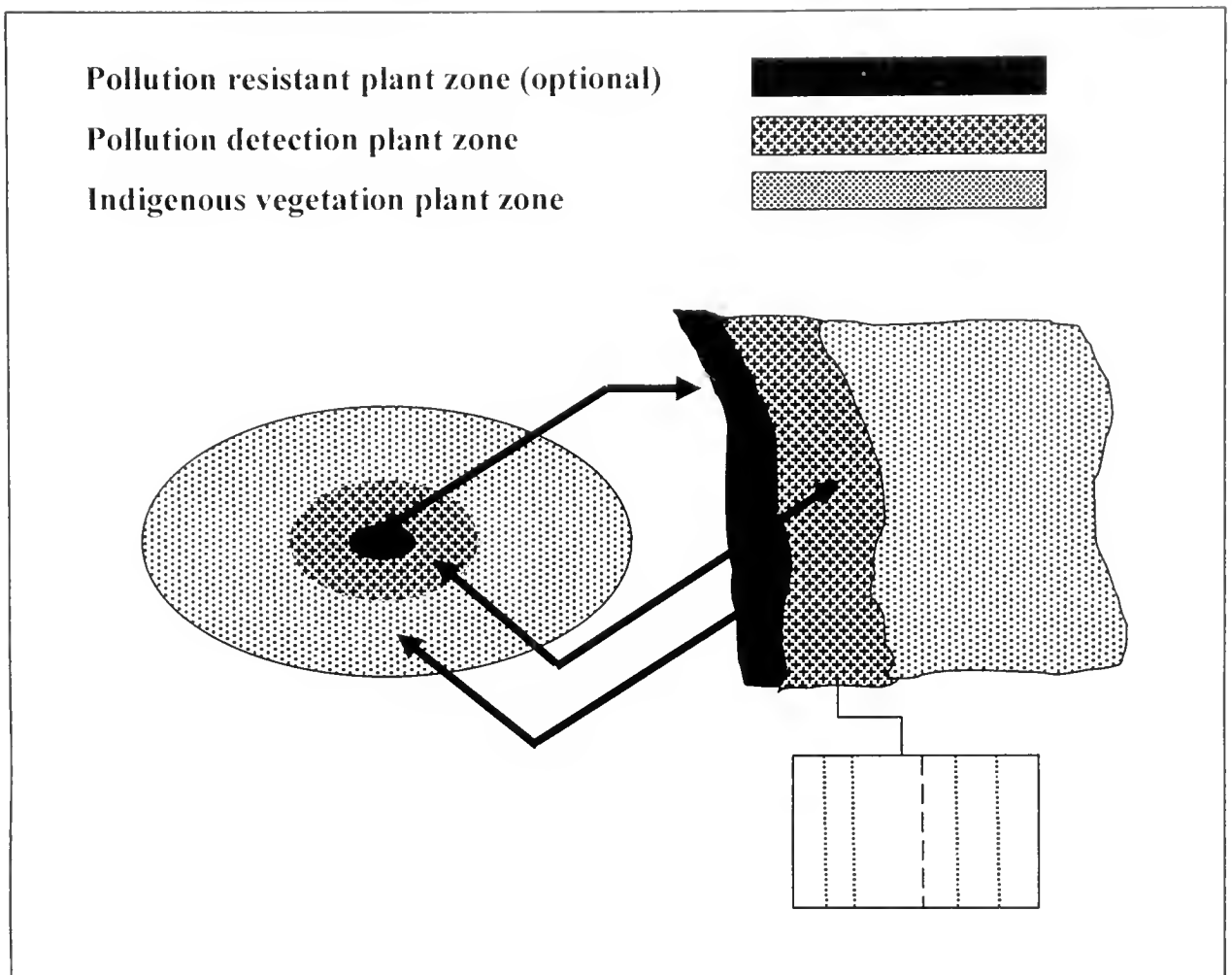
### **Buffer Zones**

Various types of buffer zones have been implemented for protective areas for several decades.<sup>4</sup> The term “buffer zone” first appears to have become widely used with the Man and Biosphere program and the Biosphere Reserves in the 1970s, which aimed to set a scientific basis for the improvement of the relationships between people and their environment globally.<sup>5</sup> Buffer zones are often created to enhance the protection of a conservation area. Buffers are commonly used in a variety of social functions, in addition to attempting to control air and water quality.<sup>6</sup>

Shafer<sup>7</sup> and others<sup>8</sup> have pointed out that buffer zones can remedy some impacts but not others, and social obstacles can further limit their effectiveness. Protected areas are supposed to be safe havens. However, at the present time, protected areas are generally not considered as islands that are safe from negative external effects such as air or water pollution from industrial activities, which can have serious impacts on species and habitats within them. Shafer noted that the science of buffer zones is very immature and deserves more attention and stated that a comprehensive, overall protected area strategy must include more than just buffer zones.<sup>9</sup> Polyakov *et al*<sup>10</sup> found that buffers often fail to perform their protective functions due to low adaptability of their designs to local settings. This was caused by inadequate understanding of the conditions under which (riparian) buffers perform the best at field scale. Clearly, buffer zones have not been designed to guarantee the same level of protection expected for the pH control from buffers used in chemistry laboratories. However, buffer zones could be designed to take better advantage of the natural ability of certain plants to bioaccumulate, degrade, or render harmless contaminants in the air, water, or soil.

### **Multi-zone Biomonitoring Buffer Concept**

Figure 1 introduces a multi-zone concept combining biomonitoring with buffering and expanding the function of buffer zones to block the transport of pollution from external sources.



**Figure 1.** Multi-zone Biomonitoring Buffer Concept. The pollution detection plant zone is shown in the figure to contain two subzones including three layers each of which might be comprised of sublayers of different types of vegetation.

The origin of pollution from point sources is represented in the center of concentric ellipses. Pollution from non-point sources, including *e.g.*, transportation corridors, originates at the inside edge of the linear/curvilinear strips. An optional **pollution resistant plant zone** could serve as the first protective barrier, depending upon trade-offs between the benefits of pollution resistance and possibly undesirable characteristics of tolerant varieties or some non-native plants. Invasive plants would be excluded because they can alter habitats and reduce biodiversity by choking out other plant life, putting pressure on native plants and animals, including threatened species that may succumb. The **pollution detection plant zone** can be a series of subzones including *e.g.*, two or three layers each of which might be comprised of sublayers of different types of vegetation. Legal permits for anthropogenic activities could possibly allow pollution excursions to penetrate the first layer of the pollution detection plant zone, which could be comprised of somewhat resistant plants, but

not allow pollution to occur in the very sensitive plants comprising the next sub layer within this zone. Hence, the first two zones would serve to protect the **indigenous vegetation zone** from pollution damage. Carefully designed plant studies will be required to set up the pollution detection plant zone. In addition to forests and urban forests, bodies of water, such as bays, canals, channels, falls, gulfs, lakes, rivers, and straits — which are not sources of pollution — could possibly benefit from the first two zones.

Multi-tier buffer concepts are not new. For example, multi-tier buffers are used in riparian areas.<sup>11</sup> These strips of land — riparian buffers — that separate upland or hill slope areas from streams, lakes, or wetlands are managed for the purpose of removing pollutants from runoff or groundwater; they are not designed with provisions for biomonitoring.

The multi-zone concept should enhance the ecological network concept that was developed in Europe to counteract physical fragmentation, which jeopardizes the viability of ecosystems and species populations.<sup>12</sup> Although the ecological network concept was primarily created for rural areas, it has also been studied for application in urbanized areas. A diagram of the ecological network concept is shown in Figure 2.

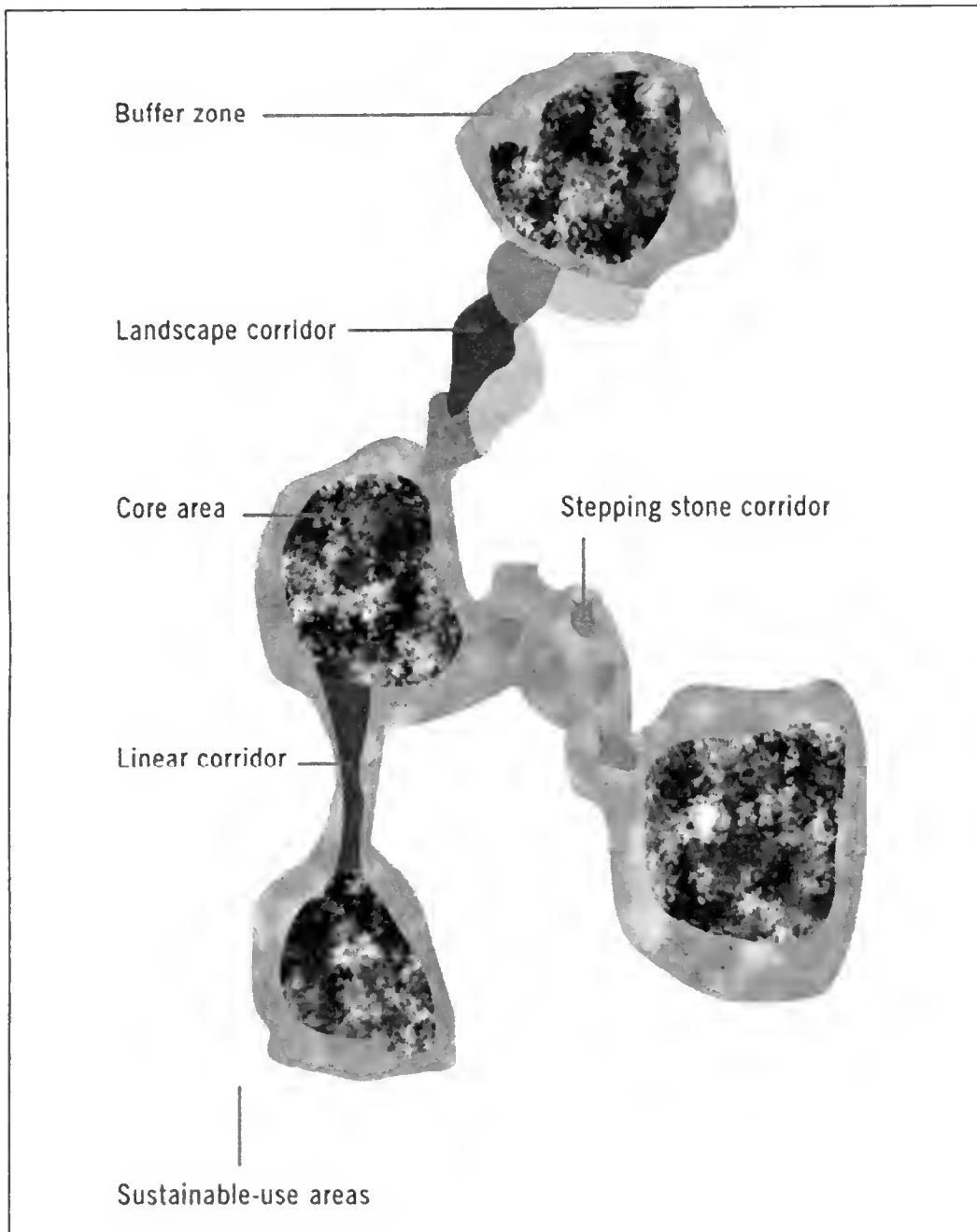
The *core areas* are the protected areas, which are connected by corridors that allow the movement of animal and plant species between the core areas, and both are surrounded by buffer zones. The corridors can include long, uninterrupted strips of vegetation, which are termed *linear corridors*; *stepping stone corridors*, which are small, non-connected habitats used to find shelter, food, or for rest; and *landscape corridors* that are strips of habitat that connect isolated patches of habitat.

Substantial benefits should accrue from transforming the buffer zones in the ecological network concept into the more effective multi-zone biomonitoring buffer zones shown in Figure 1. In other words, substituting the multi-layer buffer zones for the weaker buffer zones in the ecological network model could stop negative external effects, such as air or water pollution, on protected areas — which can have serious impacts on species and habitats within them.

The multi-zone concept should also enhance the greenways<sup>13</sup> concept that was developed in the United States. The term greenways refers to:

“a system of interconnected linear territories that are protected, managed and developed so as to obtain ecological, recreational, historical and cultural benefits”, or

a “system of routes dedicated to non-motorized traffic connecting people with landscape resources (natural, agricultural, historical-cultural) and the centres of life (public offices, sport and recreational facilities, *etc.*) both in the urban areas and in the countryside.”<sup>14</sup>



**Figure 2.** Diagrammatic representation of the spatial arrangement for an Ecological Network.<sup>15</sup> Here the core area is comparable to the indigenous vegetation plant zone shown in Figure 1, and the corridors might be equivalent to the pollution resistant or pollution detection plant zones.

Greenways are frequently corridors within an urban, suburban, or rural context, slotted into an artificial landscape. Greenways generally develop along linear structures or elements already present in the surrounding landscape, such as natural corridors (rivers, valleys, and ridges), disused railways, canals and embankments, and panoramic roads or minor rural roads.<sup>16</sup> Therefore, they offer the advantage of being easily established even in areas that are critical in terms of competition for space. Both ecological networks and greenways are linear structures crossing the landscape; both perform a connecting function in that they are elements created for migration and movement (in one case of flora and fauna and in the other of humans); and both generally contain vegetation.<sup>17</sup> Note, however, that the application of the multi-zone buffering concept to greenways and ecological networks would likely limit the range of human activities that are currently permitted in the vicinity of conventional buffer zones.

### **Discussion**

The multi-zone biomonitoring buffer concept is essentially a biological filtering system with inherent pollution detection and monitoring capabilities. Its applications are not limited to ecological networks. It can also enhance the numerous other conventional vegetative buffer concepts, *e.g.* riparian buffers. It can permit easy sampling and long term monitoring without the need for expensive equipment. It does not require new technology or exotic materials to be developed to test its implementation. It is a novel concept combining proven elements that has not been discussed or reported in the literature.

There are several possible reasons why this concept has not yet been engineered effectively into a useful system. The most likely include: (1) resistance to creating or expanding buffers for protected areas due to the politics of land use in buffer zone communities; (2) historically ineffective permitting systems for siting and operating industrial facilities or regulating effluents from human activities; and (3) the sophisticated nature of plant studies. These and other reasons are discussed below.

### **Politics of Land Use**

There is ample evidence in the literature that modifications to buffer zones perceived as imposing additional human restrictions or expanding restricted areas may require effective negotiations, additional resources, and other obstacles that could delay implementation. In Africa, buffer zone projects were sometimes viewed as coercive forms of

conservation practice that often constitute an expansion of state authority into remote rural areas.<sup>18</sup> Reporting on the historical, scientific, social, and legal aspects of U.S. National Park Buffer Zones, Shafer observed that a social climate opposing federal initiatives that intrude on the rights of private landowners was the primary obstacle to creating park buffer zones and connecting corridors.<sup>19</sup> Singh conducted research on the role of buffer zones in protected areas in Nepal. He observed:

The early concept of buffer zones was focused on the protection of protected areas from external pressures, particularly human created pressures. The main emphasis was to establish restrictions on the utilisation of park resources. This system did not become very successful ... problems are present with the growing populations within and in the immediate vicinity of the protected areas in Nepal and degraded resources in public and private lands which are considered the root causes of illicit harvesting of park properties.<sup>20</sup>

Finally, Bennett and Mulongoy<sup>21</sup> concluded that although the concept of a buffer zone may be straightforward, its design and its functioning in practice can raise many challenges. Adequately understanding the interaction between human activities and species populations and the resulting dynamics is a complex issue; determining appropriate land uses is therefore far from easy. Decisions to restrict human activities in buffer zones will also impose costs on the landowners and users, raising the question of compensation.

### **Historically Ineffective Permitting**

As mentioned above, implementation of the multi-zone biomonitoring concept envisions the effective enforcement of legal permits to possibly allow pollution excursions to penetrate the first layer of the pollution detection plant zone. This layer could be comprised of somewhat resistant plants. The permits would not allow pollution to occur in the very sensitive plants comprising the next sub layer within the pollution detection zone. Alternatively, some other arrangements could be designed to protect the indigenous vegetation zone.

Permit systems for siting and operating point source facilities and for (non-point source) diffuse sources of pollution are known to be frequently ineffective due to loopholes, enforcement failures, and other flaws.<sup>22</sup> Point sources are easier to regulate, but many old factories and

plants stand as monumental examples of the failed vision and politics of the siting process. Fortunately, the siting of noxious, hazardous, and nuisance facilities tends to draw additional scrutiny and public attention.

Ideally, the best solution is to change the pollution production source so that no harmful emissions are released to the environment. This is possible today for some manufacturing and production processes and vehicles (excluding tire dust). Alternatively, when that is not possible, the permit authorities should plan for the environmental consequences that could occur over the operating life of the source, and possibly beyond the life of the source, and ensure that permit provisions are enforceable. This should include taking into account the physical, chemical, and temporal nature of the pollutant stressors and providing for effective means of preventing environmental pollution in the event of the failure of primary containment. Based on past history, predicting future environmental consequences might require research, new forecasting methods and skills, and/or negotiating permits of shorter durations. The following paragraphs illustrate the potential dilemma.

Under the Clean Air Act, federal officials responsible for management of Federal Class I parks and wilderness areas have an affirmative responsibility to protect the air quality related values (AQRVs) (AQRVs may include vegetation, wildlife, water quality, soils, and visibility) of such lands, and to consider whether a proposed major emitting facility will have an adverse impact on such values. The term AQRV originated in the Clean Air Act Amendments of 1977 in the provisions called Prevention of Significant Deterioration (PSD).

The PSD process requires land managers to predict AQRV changes that would likely occur if a pollution source were built with the pollutant emissions levels proposed in the permit. This predictive requirement presented a challenge in using ecosystem-based AQRVs such as lichens in the PSD process because no models were available that quantitatively predicted how incremental changes in air chemistry can affect site and species-specific lichen condition or viability in the future.

### **The Sophisticated Nature of Plant Studies**

There are two distinct problem areas to be considered here: buffer design and meaningful bioindicators.

Although there is a substantial literature base, there are no cookbooks for designing buffers. A large body of scientific knowledge exists to help guide the planning and designing of buffers. This



information is widely dispersed throughout the vast research literature and is not easily accessible or usable for most planners. For example, Bentrup prepared a guide with over 80 design guidelines developed from more than 1,400 research articles from disciplines as diverse as agricultural engineering, conservation biology, economics, hydrology, landscape ecology, social sciences, and urban ecology.<sup>23</sup>

Biomonitoring could appear to some observers to be the domain of do-it-yourself Ph.D. scientists who spent years studying its intricacies.

De Temmerman *et al*<sup>24</sup> report that lack of standardization is probably one of the major reasons why biomonitoring techniques are less used in legislation than methods based on physico-chemical monitoring. They noted, however, that both techniques are complementary because physico-chemical monitors measure pollutant concentrations or deposition fluxes, whereas biomonitors reflect effects.

Cape<sup>25</sup> discusses when and when not to use plants as bioindicators, and illustrates some of the precautions required if meaningful conclusions are to be inferred. He notes that the sound interpretation of measurement data relies on a clear understanding of what such 'biomonitors' can and cannot demonstrate, and the limitations of each approach. Details are available in *Relating Atmospheric Source Apportionment to Vegetation Effects: Establishing Cause and Effect Relationships*.<sup>26</sup>

Choosing the plants for the pollution resistant and pollution detection zones associated with the multi-zone biomonitoring buffer concept will require carefully designed pilot studies. However, no new technology would be required.

### **Future Directions**

Testing the multi-zone biomonitoring buffer concept could occur through pilot studies conducted at various sites and scales. Rapid detection and delineation of contaminants in urban settings is critically important in protecting human health.<sup>27</sup> Big urban parks can act as buffer zones between highways and residential areas. However, town and city streets are not ideal laboratories. Urban forests are increasingly being seen as an important infrastructure that can help cities remediate their environmental impacts.<sup>28</sup> Buffer zones and riparian buffers in protected areas, greenways, and ecological networks could be ideal sites for testing.

What happens across the borders can dramatically impact the environment within protected areas. For example, proposals to site an

open pit mine or gold mine next to a remote national park are likely to cause concerns by people familiar with Silver Bow Creek, Oregon's Formosa Mine, or other past and present Superfund sites on the EPA's National Priorities List. Information about the vegetation in the areas surrounding some of those sites is likely to yield numerous candidate plant (and soil) indicators, which might be used to guide decisions concerning proposed projects — and possibly, if a project is approved, the selection of vegetation for use in a multi-zone biomonitoring project.

Opportunities may exist for collaboration with new or established monitoring programs for local and industrial sources of pollution. Programs on the local scale can require less effort due to a relatively easily located point source from which contamination generally follows a gradient. In this instance, cause and effects relationships are often obvious. In large-scale surveys, other factors such as uneven spatial distribution and pollutant mixtures become more significant. However, large-scale standard monitoring programs can be important in providing data on long-term temporal and spatial trends of air pollutants.

The multi-zone biomonitoring buffer concept could potentially become a simple and inexpensive process which lends itself as a potent, adaptable method of assessing air quality in developing countries. However, due to climatic and edaphic (soil characteristics) differences, additional considerations may be necessary. For example, in arid areas flora may be less sensitive to air pollution because of low humidity. Biological monitoring becomes highly applicable in remote areas where continuous direct air sampling is expensive and impractical.

Laboratory and/or additional field investigations may be necessary to establish the role of individual pollutants, the synergistic effects of pollutant mixtures, and biological responses and tolerances. These studies can be used to establish parameters of biological monitoring programs conducted under natural conditions.<sup>29</sup>

The pilot study initiated here could be considered a jumping off point for a long-term study to continue to validate and refine the concept.

### **Conclusion**

Human activities have been contributing increasingly to habitat destruction, degradation, and fragmentation. Effective habitat management and maintenance measures are needed to reverse this trend. Such measures include *inter alia* coherent and comprehensive environmental control and management systems; sufficient financial and technological support;

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transparent effective permitting systems; and effective enforcement. This paper describes a concept for combining the biomonitoring ability of plants with their capacity to block the transport of pollutants before they can contribute to habitat degradation. This multi-zone biomonitoring buffer concept, when implemented through an effective permit system, can contribute to preventing damage and providing stability to protected areas.

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## Bio

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# Newton's Rotating Water Bucket: A Simple Model

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## Abstract

Isaac Newton proposed hanging a bucket of water by a cord in the *Principia*. If the cord is twisted and the bucket is then released, it begins to spin and the surface of the water acquires a paraboloidal shape. In this paper, the parabolic profile as a function of the angle of rotation is derived, as well as the period of the torsional oscillations as a function of the initial parameters of the system.

## 1. Introduction

*IF A VESSEL, hung by a long cord, is so often turned about that the cord is strongly twisted, then filled with water, and held at rest together with the water... [then] while the cord is untwisting itself... the vessel, by gradually communicating its motion to the water, will make it begin sensibly to revolve, and recede by little and little from the middle, and ascend to the sides of the vessel, forming itself into a concave figure (as I have experienced) and the swifter the motion becomes, the higher will the water rise ... This ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water ... becomes known, and may be measured by this endeavor. [1]*

Newton's bucket is well known to philosophers of science, who have pondered the metaphysics of why the liquid in a rotating container adopts a curved surface. Ernst Mach, for example, postulated that the parabolic shape must be due to the existence of matter in the universe.

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specifically of the distant “fixed stars” relative to which the bucket rotates. [2] However, the simple physical questions are: How does the shape of the water surface vary as the cord supporting the bucket unwinds? What is the period of the torsional oscillations?

## 2. Surface Profile From a Force Analysis

Suppose water partly fills a right cylindrical bucket (of radius  $R$ ) that is rotating about its vertical  $z$  axis of symmetry at angular speed  $\omega$ . Make the key assumption (to be discussed later) that the liquid instantaneously follows the motion of the bucket. (The speed of the bucket is restricted to be less than some value  $\omega_{\max}$  that prevents both the spinning water from spilling over the top edge, and the bottom of the bucket from being exposed at the axis of rotation.) Denote the cylindrical coordinates of any point on the surface of the water as  $(r, \phi, z)$  where the origin lies on the axis at the bottom of the bucket. The axes are fixed in the laboratory frame and do not rotate with the bucket. The angular speed of the water and bucket is  $\omega = d\phi/dt$ . Two forces act on a bit of water at the surface. One is gravity vertically downward. The other can be alternatively described as being due to the pressure from the surrounding water [3], as a buoyant force [4], or simply as a normal force [5]. The resultant of the two forces is a radially inward centripetal force [6] in the inertial laboratory frame, or equivalently a radially outward centrifugal force [7] in the noninertial frame of the bucket. By considering the vertical and horizontal components of Newton’s second law [8], one finds that the water surface adopts the paraboloidal shape

$$z = z_0 + \frac{\omega^2 r^2}{2g} \quad (1)$$

where  $g = 9.80 \text{ m/s}^2$  is Earth’s gravitational field strength and  $z_0$  is the height of the water at the center of the spinning bucket. (Another way to derive this result is to note that the surface of the water must be an equipotential relative to the sum of the gravitational and centrifugal potential energies [9].) The value of  $z_0$  can be related to the total mass  $m$  of water in the bucket,

$$m = 2\pi\rho \int_0^R r z dr \quad (2)$$



where  $\rho = 1000 \text{ kg/m}^3$  is the density of water. Substituting Eq. (1) into (2) and performing the integral gives

$$m = \pi \rho R^2 \left( z_0 + \frac{\omega^2 R^2}{4g} \right). \quad (3)$$

Denote the height of the water in the bucket when it is stationary by  $h$ . Then putting  $\omega = 0$  in Eq. (3) implies

$$m = \pi \rho R^2 h, \quad (4)$$

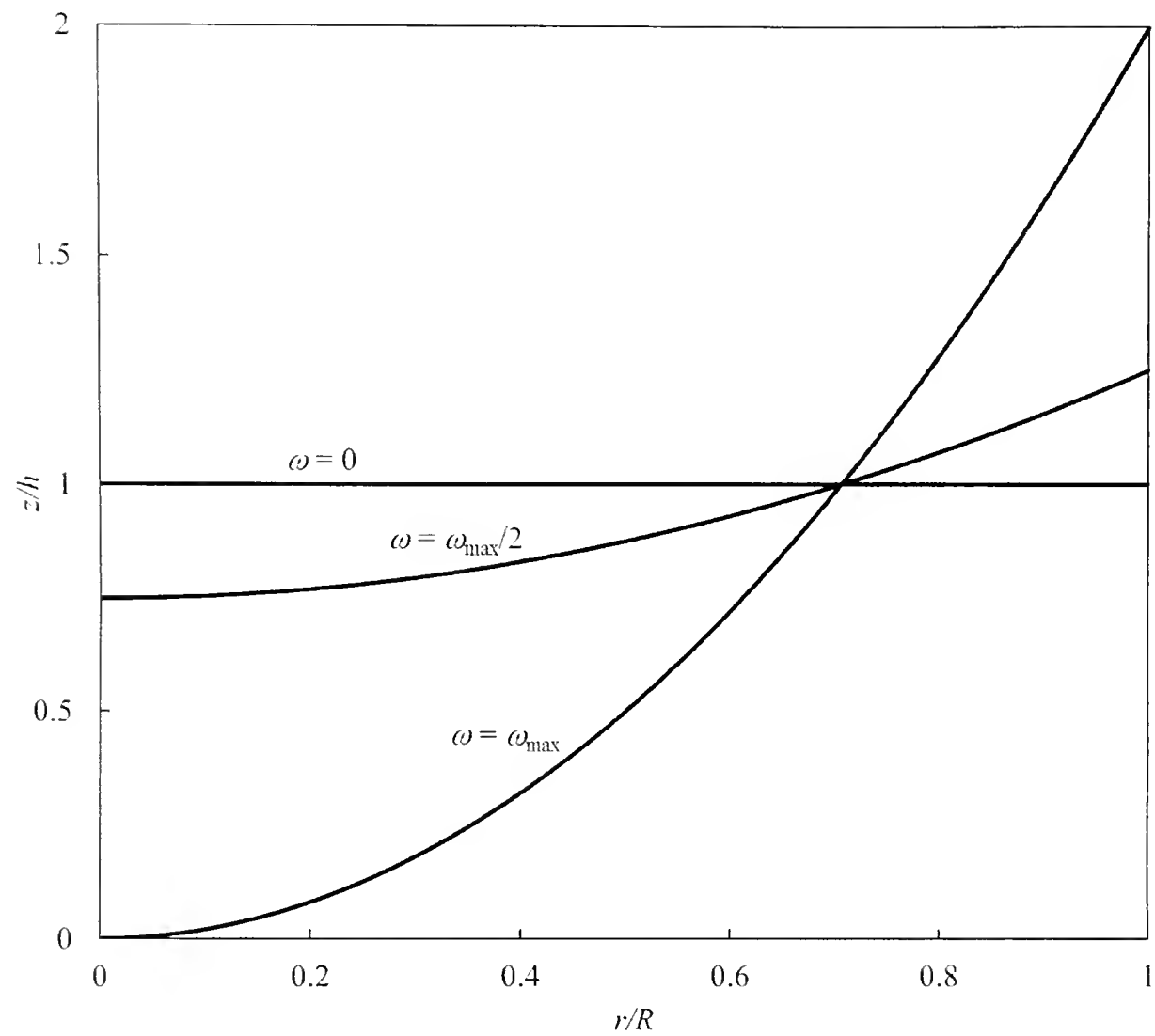
so that Eq. (3) can be rearranged as

$$z_0 = h - \frac{\omega^2 R^2}{4g}. \quad (5)$$

Substituting this result into Eq. (1) leads to the normalized expression

$$\frac{z}{h} = 1 - \frac{\omega^2}{\omega_{\max}^2} \left( 1 - \frac{2r^2}{R^2} \right) \quad (6)$$

where  $\omega_{\max} \equiv 2R^{-1}\sqrt{gh}$ . Note that  $z = 0$  at  $r = 0$  when  $\omega = \omega_{\max}$ , in agreement with the parenthetical discussion of  $\omega_{\max}$  above Eq. (1). Also note that  $z/h = 2$  at  $r = R$  when  $\omega = \omega_{\max}$ , which implies that the bucket must initially be filled no more than halfway with water, to prevent liquid from spilling out at the maximum angular speed. Equation (6) is plotted in Figure 1 for three different values of  $\omega/\omega_{\max}$ . For any angular speed,  $z = h$  when  $r/R = 2^{-1/2}$ . As the bucket spins faster, the water level drops in the center and rises up near the walls, as Newton noted.



**Figure 1.** Profiles of the water surface for three different angular speeds.

**3. Angular Speed From an Energy Analysis**

The moment of inertia of the water in the spinning bucket is

$$I = \int_0^R r^2 2\pi\rho r z dr = I_0 \left( 1 + \frac{\omega^2}{3\omega_{\max}^2} \right) \tag{7}$$

using Eqs. (4) and (6), where the moment of inertia of the water when the bucket is at rest is  $I_0 = mR^2 / 2$ . The moment of inertia increases as water is flung farther away from the axis of rotation with increasing angular speed, up to a maximum value of  $4I_0 / 3$ .

Just as the elastic potential energy of a spring with a particle attached to its end is  $kx^2 / 2$  where  $x$  is the translational displacement of

the particle and  $k$  is the spring constant, so the torsional potential energy of the rope with the bucket attached to its end is

$$U_T = \frac{1}{2} c \phi^2 \quad (8)$$

where  $\phi$  is the angular displacement of the bucket and  $c$  is the torsional constant of the rope. The gravitational potential energy of the water relative to the bottom of the bucket is

$$U_G = \int_0^R \int_0^z 2\pi \rho r dz dr g z = \pi \rho g \int_0^R r h^2 \left( 1 - \frac{\omega^2}{\omega_{\max}^2} + \frac{2\omega^2 r^2}{\omega_{\max}^2 R^2} \right)^2 dr \quad (9)$$

using Eq. (6). With the help of Eq. (4), the integral simplifies to

$$U_G = \frac{mgh}{2} \left( 1 + \frac{\omega^4}{3\omega_{\max}^4} \right) \quad (10)$$

which reduces to the expected result if  $\omega = 0$ . Note the seemingly paradoxical fact that even though the water is cylindrically symmetric and  $U_G$  is therefore independent of  $\phi$  as measured in the *rotating frame of the bucket*,  $U_G$  is a function of  $\omega$  which in turn depends on the angle  $\phi$  as measured in the *inertial frame of the laboratory*. The resolution of this paradox is that the angular acceleration is presumed to be small enough that  $z$  can be taken to be independent of  $\phi$  over any  $2\pi$  range, and yet the height of the water at a given radius varies over the course of many revolutions of the bucket. As noted in Ref. [7], water in a 9-cm-diameter Lucite cylinder spinning at a constant rate of 300 rpm takes about 1 minute to attain its equilibrium paraboloidal shape, indicating that the coupling between  $z$  and  $\phi$  is weak but nonzero.

Assume that the mass of the bucket is negligible compared to that of the water. Then the total potential energy  $U$  of the system is the sum of  $U_T$  and  $U_G$ . Suppose that the rope is twisted through an initial angle  $\phi_0$  and the bucket is released from rest, so that the initial kinetic energy is  $K_i = 0$  and the initial potential energy is

$$U_i = \frac{1}{2} c \phi_0^2 + \frac{1}{2} mgh. \quad (11)$$

When the rope has untwisted to some angle  $\phi$  so that the bucket is rotating at angular speed  $\omega$ , the kinetic energy is

$$K_f = \frac{1}{2} I \omega^2 = \frac{1}{2} I_0 \omega^2 + \frac{I_0}{6 \omega_{\max}^2} \omega^4 \tag{12}$$

according to Eq. (7), and the potential energy is

$$U_f = \frac{1}{2} c \phi^2 + \frac{1}{2} mgh + \frac{mgh}{6 \omega_{\max}^4} \omega^4. \tag{13}$$

Conservation of energy now implies that

$$c \left( \phi_0^2 - \phi^2 \right) = I_0 \omega^2 + \frac{I_0 \omega_{\max}^2 + mgh}{3 \omega_{\max}^4} \omega^4. \tag{14}$$

Noting that  $I_0 \omega_{\max}^2 = 2mgh$ , we can rearrange Eq. (14) into the normalized form

$$\frac{\omega^4}{\omega_{\max}^4} + 2 \frac{\omega^2}{\omega_{\max}^2} = \frac{c \phi_0^2}{mgh} \left( 1 - \frac{\phi^2}{\phi_0^2} \right). \tag{15}$$

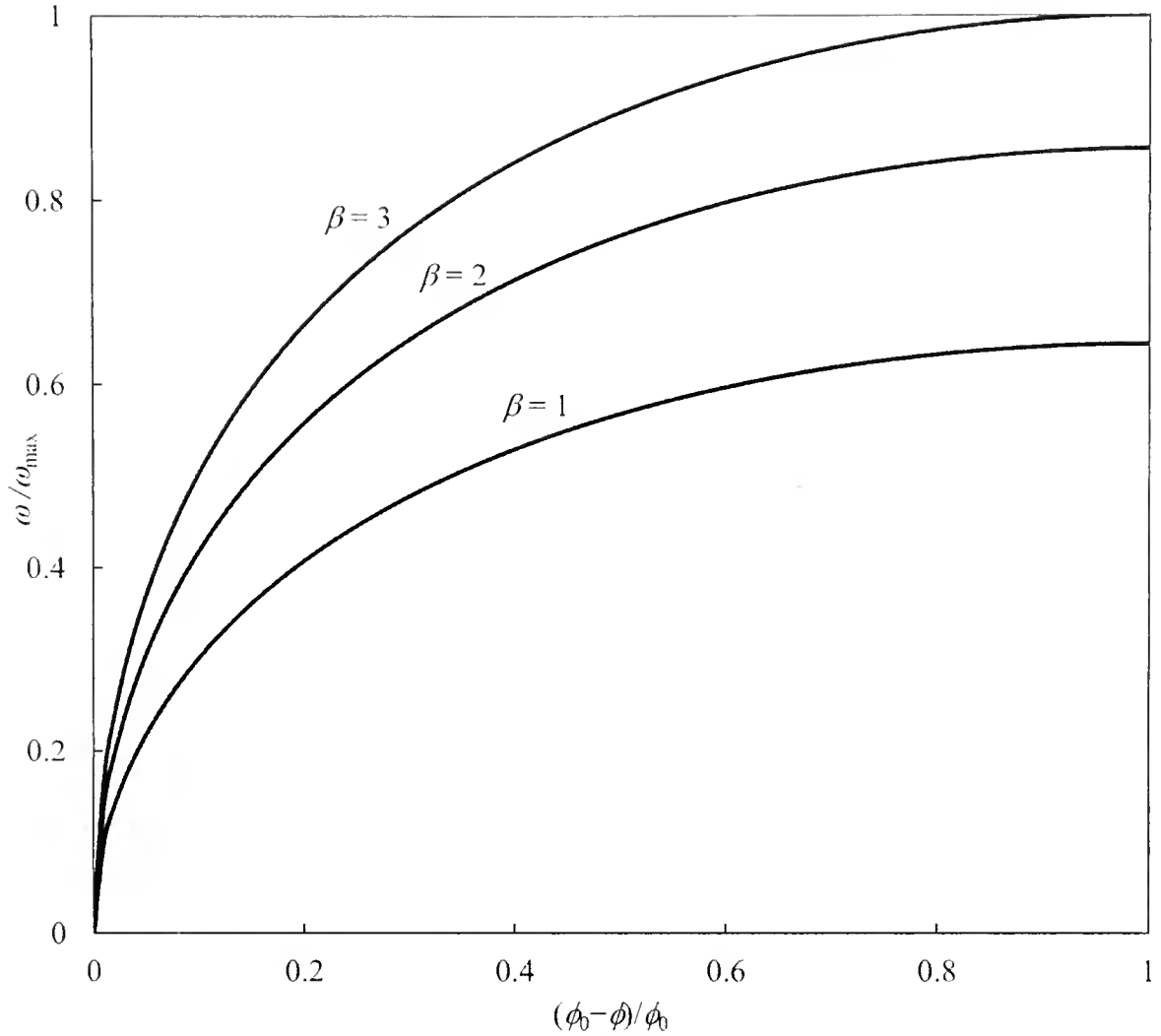
Solving this biquadratic equation gives

$$\frac{\omega^2}{\omega_{\max}^2} = \sqrt{1 + \beta \left( 1 - \frac{\phi^2}{\phi_0^2} \right)} - 1 \tag{16}$$

where

$$\beta \equiv \frac{c \phi_0^2}{mgh}. \tag{17}$$

The dimensionless constant  $\beta$  is the ratio of the initial torsional potential energy  $c \phi_0^2 / 2$  to the initial gravitational potential energy  $mgh / 2$ . The square root of Eq. (16) is plotted in Figure 2 for three different values of  $\beta$ . Note that the maximum value of  $\beta$  is 3 if  $\omega$  is not to exceed  $\omega_{\max}$  when the cord has fully unwound at  $\phi = 0$ . Furthermore, even at the midpoint of the bucket's oscillations when  $\phi = 0$ , increasing  $\beta$  from 1 to 3 increases  $\omega$  by only 55%.



**Figure 2.** Angular speed of the water as a function of the fractional unwinding of the rope for three different initial numbers of twists of the bucket.

#### 4. Period of Torsional Oscillations

Take the square root of Eq. (16), substitute  $\omega = d\phi/dt$ , and separate variables. Then integrate over a quarter period  $T/4$  as the bucket passes through its equilibrium position and the cord fully winds back up, to get

$$\int_0^{\phi_0} \left[ \sqrt{1 + \beta \left( 1 - \frac{\phi^2}{\phi_0^2} \right)} - 1 \right]^{-1/2} d\phi = \omega_{\max} \int_0^{T/4} dt. \quad (18)$$

Multiply both sides of this equation by  $\phi_0^{-1} \beta^{1/2}$ . Then make the change of variable in the left-hand integral to  $\theta$  where  $\sin \theta \equiv \phi/\phi_0$ . Perform the right-hand integral and substitute Eq. (17) into it to eliminate  $\beta$ . Using

$\omega_{\max} = \sqrt{2mgh/I_0}$ , Eq. (18) gives the period of the bucket’s torsional oscillation as

$$T = \sqrt{\frac{8I_0}{c}} \int_0^{\pi/2} \left[ \frac{\beta \cos^2 \theta}{\sqrt{1 + \beta \cos^2 \theta} - 1} \right]^{1/2} d\theta. \tag{19}$$

The square root in the denominator inside the square brackets is approximately  $1 + 0.5\beta \cos^2 \theta$  in the limit as  $\beta \rightarrow 0$ . Denoting the period as  $T_0$  in this small-angular-amplitude limit, one immediately obtains

$$T_0 = 2\pi \sqrt{\frac{I_0}{c}} \tag{20}$$

as expected, since  $I \rightarrow I_0$  for small  $\omega$  according to Eq. (7). The integral in Eq. (19) can be numerically evaluated for nonzero  $\beta$ , but it is found to only increase slowly with  $\beta$ . Even at the maximum value of  $\beta = 3$ , the period of oscillation is merely 12% larger than  $T_0$ .

In any case, Eq. (16) gives an exact solution in phase space, whereby quantities are expressed in terms of the twist angle  $\phi$  rather than in terms of the elapsed time  $t$ . For example, substituting Eq. (16) into (6) gives the height of the water at any point in the bucket as a function of the angle that the cord has unwound. In particular, at the walls of the bucket where  $r = R$ , let  $Z$  denote the height of the water. Then the fractional rise in the height of the water at the walls above the stationary level is

$$\frac{Z - h}{h} = \sqrt{1 + \beta \left( 1 - \frac{\phi^2}{\phi_0^2} \right)} - 1 \tag{21}$$

which is equal to the normalized square of the angular speed of the bucket, according to Eq. (16). As already mentioned,  $Z = 2h$  when  $\beta = 3$  and  $\phi = 0$ .

### 5. Closing Remarks

Why is the period 12% longer for large-angle oscillations of this torsional pendulum than it is for small amplitudes? The reason is *not* the same as for a simple pendulum. For a simple pendulum, the period increases because the approximation  $\sin \theta \approx \theta$  breaks down at large

angles. Instead, the reason here is the increase in the moment of inertia of the water, in accordance with Eq. (7). In particular, if we froze the water, then the period would be independent of amplitude, just as it is for a mass on a Hookean spring.

Finally, let's return to the key assumption underlying the analysis. The viscosity of the water must be high at the walls and bottom of the bucket if the fluid is to instantaneously adjust to the motion of the solid container. At the same time, the viscosity needs to be low within the bulk of the fluid to prevent differences in angular speed between one region of the water and another. Fortunately, simulations for the spin of an incompressible fluid in a cylindrical container suggest that there are viscid boundary layers in the water near the solid surfaces of the cylinder, accompanied by an inner inviscid core [10]. The situation is similar to laminar flow over an airplane wing, with drag motion close to the wing and potential flow far away from it.

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### Bios

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# An Examination of Historical and Current Laws Governing Leporids

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## Abstract

Leporids (rabbits and hares) are usually assumed to be abundant; however, some populations in North America are declining. Over time, the human use of leporids has involved trapping, breeding, and consumption. Now there are increasing concerns about the conservation of leporids. Wildlife laws can assist with the management of wildlife declines, as they underpin how leporid populations are regulated. There has been little research regarding how and why certain jurisdictions developed in the context of leporid conservation. In order to improve conservation efforts, a historical legislative baseline must be understood. This study examined the historical underpinnings of 19<sup>th</sup> century legislation regarding leporids in the United States by examining published wildlife laws, including hunting regulations, scalp laws, and laws related to the possession of game — and also the violation of those laws. The study revealed that leporid legislation during the 19<sup>th</sup> century in the United States focused on the regulation of take through either bounty limits or limiting hunting seasons. The findings provide an understanding of why people could not hunt leporids during certain seasons, why people could not hunt with ferrets, and why leporid meat could not be sold during certain times of the year.

## Introduction

**WILDLIFE LAWS** impact how wildlife populations are regulated (Coggins 1978) and how species are treated (Linder 1988), and they also impact organismal biology, the economy, and certain social factors (Coggins 1978). For example, wildlife laws regulate population size through the use of bag limits and hunting seasons; the selling and shipment of game meat contributes to the economy.

Leporids (rabbits and hares) are prey species, game species, herbivores, and maintainers of the ecosystem, and they contribute to the diversity of floral species in the ecosystem (Zedler and Black 1992, Lees and Bell 2008). Historically, leporids were “in abundance” in the United States (*e.g.*, Hallock 1883, Bailey 1908) and, in fact, they were so abundant that numerous “rabbit drives” were held for jackrabbits across the United States (Palmer 1896). Today, however, almost one in four

species of the Order Lagomorpha — which includes rabbits and hares (Leporidae), and also pikas (Ochotonidae) — are threatened (IUCN 2013a).

Since laws impact wildlife populations, it is imperative to examine the historical underpinnings of legislation relating to leporids. The 19<sup>th</sup> century was an interesting time period in the United States as people immigrated into the country, settlement began to develop, and states joined the Union. The conversation on historical wildlife laws seems to focus on who had the power to regulate wildlife law or who had the power to hunt (*e.g.*, Lund 1976, Lueck 1989, Lueck 1995); however, there has been little research on how and why historical laws pertaining specifically to leporids were developed and approached. In particular, there is little understanding of how decisions were made, why people could not hunt leporid species during certain seasons, why people could not hunt with ferrets, or sell meat during specific times of the year.

The aim of this paper is to clarify how and why certain leporid legislation was implemented. First, the paper lists the laws and regulations pertaining to leporids from 1800 to 1900, followed by an analysis of these laws, including those for protecting or hunting leporids, hunting with ferrets, and selling meat. Since a historical analysis is valuable in order to understand current laws (Bean and Rowland 1997), the paper includes a comparison of current and historical leporid legislation. Finally, in order to examine historical laws, it is necessary to examine a state example to assess how the historical laws worked in practice (*i.e.*, violations that occurred with legislation); therefore, New Jersey is used as an example of how often the rabbit laws were violated from the 4-year period from 1896 to 1900. Historical information can play an important role in conservation efforts and could be better incorporated into conservation studies (Meine 1999, Szabó and Hédli 2011).

In conducting this research, electronic academic databases were searched under the terms “rabbit laws” and “rabbit scalps” from 1836 to 1900 through the Library of Congress website for historical newspapers. Identified laws were typed into Google Books and searched over the years 1800-1900 and additional materials were identified, including peer reviewed publications and government published articles. The study methodology was based on the historical research method which involved the validation of data (Leedy and Ormrod 2010). Therefore, the newspapers and articles were examined for external evidence and carefully chosen as primary sources. Once articles were deemed genuine,

internal evidence dealt with interpreting the historical information, and this involved listing assumptions to guide interpretation of the data (Leedy and Ormrod 2010). The following assumptions guided the interpretation of the data for this research: the laws echoed the need for people to protect their assets, and protect leporids for the future as people enjoyed hunting them; and, many wildlife populations were undervalued at the time (as described by Lueck 1989). A process for analyzing qualitative research was applied in which the data were coded, and items with closely linked concepts were categorized (Holloway 1997). For example, laws relating to protection/ ferrets/ hunting dates/ selling meat were coded as a “1”; laws relating to bounties were coded as a “2”; and laws relating to “other” were coded as a “3.”

### **19th Century Laws Relating to Leporids**

A summary of the laws pertaining to leporids in the United States from 1820 to 1899 is presented in Table 1.

As shown in Figure 1, the majority (66%) of the laws from 1820 to 1899 focused on the protection of rabbits. Others allowed scalping.

Further analysis revealed that the eastern United States focused on the protection of rabbits or hares with season dates, bag limits, banning the use of ferrets during hunting, and/or restricting game sales. The western states focused on bounties, and the counties paid money to individuals who captured jackrabbits.

Many of the laws were of county jurisdiction (see Table 1). Counties imposed fines or jail time for individuals who disobeyed the law. The more lenient laws involved \$1-\$5 fines or jail for 10 days.

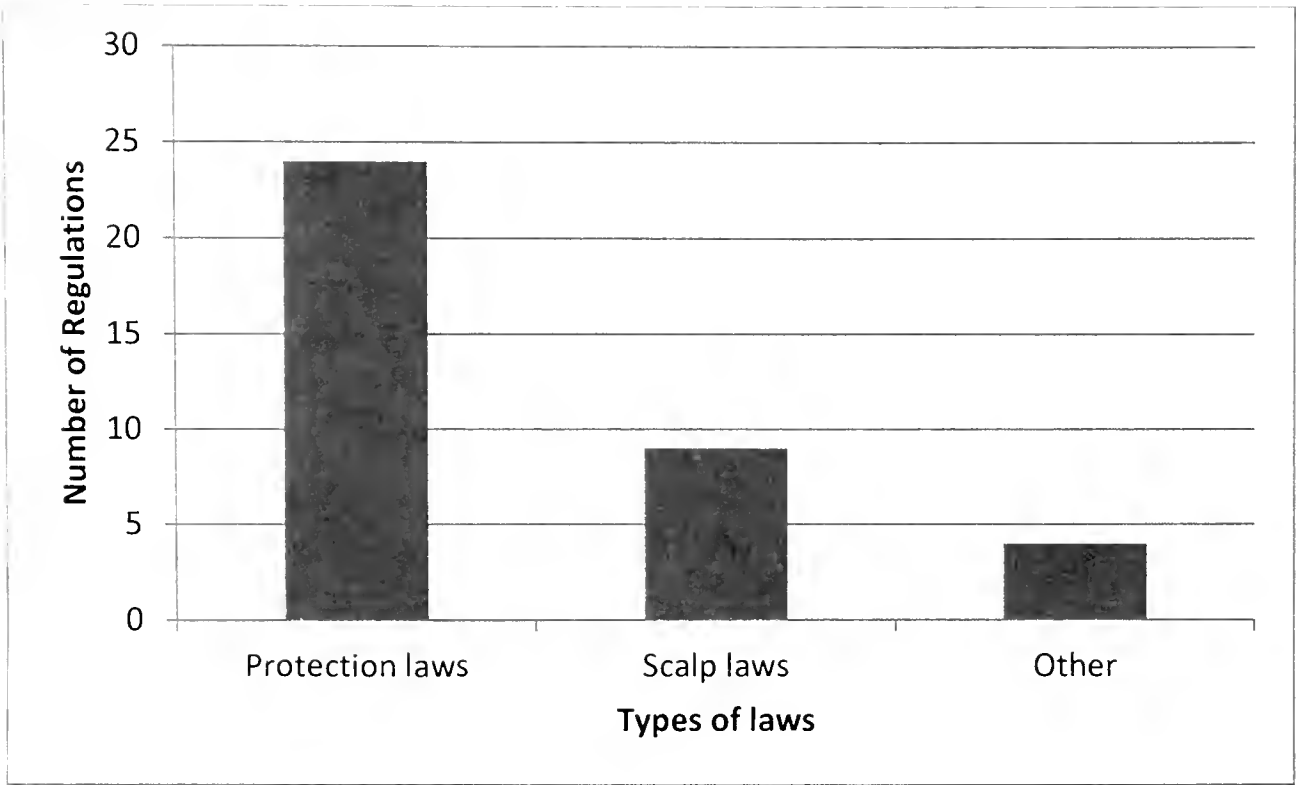
It was also apparent that the earlier 19<sup>th</sup> century laws concentrated on hunting seasons and methods of capture. In the laws listed in Table 1, the leporid hunting season lengths ranged from 4 months to more than 2 years. The later 19<sup>th</sup> century laws dealt with the export and sale of game (Palmer and Oldys 1900).

**Table 1.** Summary of U.S. laws pertaining to leporids, 1820-1899

| State         | Year | Legislation/Regulation  |
|---------------|------|---|
| California    | 1895 | Senate Bill 644 - Bounty for rabbit scalps.   |
| Delaware      | 1852 | Chapter 55, Section 11 - Cannot kill a rabbit between February 1 and October 15 in Kent or Sussex County.   |
| Hawaii        | 1890 | Legislative Assembly, Chapter 61 - Cannot keep or breed rabbits in Hawaii except people raising rabbits in a confined area and kept as pets.                                  |
|               | 1898 | Section 1483 - Cannot keep or breed rabbits unless people kept them confined and kept as pets.  |
| Idaho         | 1899 | House Bill Number 16, Section 1760 - An Act to provide a bounty for rabbits (no more than 5 cents).   |
| Kansas        | 1877 | Kansas Laws March 6, 1877 - Rabbit Scalp Bounty Act.  |
|               | 1877 | Kansas Laws of 1877, Article 18 - Authorizing a rabbit scalp bounty with amendments.  |
|               | 1885 | House Bill No. 456 - Authorizing bounty on rabbit scalps. and repeals Chapter 53, Laws of 1885.   |
|               | 1889 | March 9, 1889 House Bill No. 458 - Bounty upon rabbit scalps not to exceed 5 cents per rabbit.  |
| Kentucky      | 1873 | Chapter 46, Section 3 - Cannot kill a leporid between February 1 and October 20. Fine is \$3.   |
|               | 1874 | Chapter 76, Section 2 - Cannot kill a leporid in Bourbon County from February to August. or fined \$10.   |
| Maryland      | 1898 | 206 Section 15 D - Cannot possess or sell a leporid between December 24 and November 1. Fine is \$1-\$10 for each rabbit.   |
| Massachusetts | 1894 | Chapter 97 - Cannot kill or sell rabbits between March 1 and September 15; \$10 fine.   |
| Michigan      | 1897 | Act 282, Section 1 - Cannot use a ferret to hunt rabbits in Wayne County. The fine is \$5. or jail for 10 days or less.   |
| New Hampshire | 1899 | Chapter 131, Section 4 - Cannot kill a leporid between April 1 and September 15 or will be fined \$5 for each animal and/or possible jail time for no more than 30 days.      |
| New Jersey    | 1820 | Anyone who destroys, takes, or kills a rabbit except between September 1 and February 1 will pay \$1 for every rabbit offense.  |
|               | 1896 | Chapter 169, Section 4 - It is unlawful to have a rabbit or hare in possession except from November 10 to January 1. Penalty is \$20 for each animal killed or in possession. |

**Table 1.** Summary of U.S. laws pertaining to leporids, 1820-1899 (continued)

|              |      |   |
|--------------|------|---|
| New York     | 1880 | Chapter 584, General Statutes of New York, Section 1 - Cannot kill rabbits with ferrets.  |
|              | 1881 | Penal Code 655 - Rabbit coursing is illegal.  |
|              | 1893 | Columbia County Ordinance, Section 7 - Leporids cannot be killed between December 1 and October 1 or a fine.  |
| Oregon       | 1893 | Chapter 85, Section 4229 - Between 5 and 25 cents bounty for jackrabbits.   |
| Pennsylvania | 1876 | Pennsylvania Game Law of 1876 - Rabbits only game from October 15 to December 15.   |
|              | 1878 | No. 207, Section 3 - No one can have or sell a hare or rabbit between January 1 and October 15. Penalty is \$5 for each animal killed, and \$10 for each rabbit killed with a ferret.   |
| Rhode Island | 1882 | Chapter 95, Section 1 - Cannot kill a leporid between January 1 and September 1, and cannot use a ferret; \$5 for each offense, or jail for 10 days.  |
| Utah         | 1888 | Chapter 17, Section 1 - Bounty for jackrabbits 2 cents.   |
| Vermont      | 1894 | Section 4610 - Cannot kill a rabbit or hare between May 1 and September 1; fine \$5 for each killed.  |
| Virginia     | 1894 | Chapter 80, Section 3 - Not lawful to shoot rabbits between January 1 and November 15.  |
|              | 1896 | Chapter 323, Fairfax County - Cannot kill or capture leporids from February 1896 to January 1, 1898, but can kill or capture rabbit with traps or dogs from November 1 to January 1. Fine is \$5-\$20, and jail not exceeding 30 days until fine is paid. |
|              | 1896 | Chapter 790, Shenandoah County - Cannot kill or capture leporids between March 1 and November 1 every year. The fine is between \$10 and \$50, and may involve jail time between 30 and 60 days.  |
|              | 1896 | Chapter 853, Lancaster, Northumberland, Richmond, Westmoreland, King George Counties - Cannot kill, sell, or possess jackrabbits from May 1, 1896 to October 1, 1898. Can keep jackrabbits for breeding. Fines are \$20 and higher.                       |
|              | 1896 | Chapter 80, Section 3 - Cannot shoot rabbits between January 15 and November 15 in Accomac and Northampton Counties.  |
|              | 1896 | Chapter 388, Section 1 - Cannot kill leporids between February 1 and September 1 in Chesterfield County. Fine is between \$1 and \$5.   |
|              | 1896 | Chapter 755, Section 1 - Cannot kill, hunt, or sell leporids between February 1 and November 1 in Essex County. Fine is \$5-\$20 for each offense.  |
|              | 1896 | Chapter 323, Section 1, Fairfax County - Cannot kill, capture, or sell leporids between February 12, 1896 and January 1, 1898.  |
| Washington   | 1877 | Laws of Washington, Section 5 - Authorization for rabbit scalp bounties.  |
| Wisconsin    | 1897 | Chapter 188, Section 33 - Cannot use a ferret to hunt rabbits. Fine is between \$10 and \$25 or jail until fine is paid (not more than 30 days).  |



**Figure 1.** U.S. laws/regulations relating to leporid protection, scalping, and other purposes, 1820-1899

**Impact of Historic Regulations on Leporid Conservation**

As the research findings demonstrate, certain historic regulations have particularly impacted the conservation of leporids today, including historic regulations relating to leporid hunting and/or protection; the use of ferrets in hunting; and the sale of meat.

***Early Laws to Limit Hunting and Protect Leporids***

Both protecting and hunting leporids appeared to be controversial in the eastern United States. On the one hand, people wanted to hunt leporids and it was unclear as to why a predator or varmint could take the animal when the leporid could provide nourishment for human consumption (Annual Report of the Game Commissioners of the State of Pennsylvania 1914). At the same time, farmers and nursery owners in Ohio were upset by the protection of rabbits, as the rabbits would multiply and impede the growing of crops and trees (Annual Report of the Ohio State Board of Agriculture 1898).

On the other hand, wildlife populations in many states generally were decreasing (Dambach 1948) and it was therefore necessary to

establish hunting seasons. People wanted to protect rabbits from hunting and rabbit dogs so that they would not become scarce (Recreation 1899, Willis 1900, Recreation 1900). Dambach (1948) states that Ohio hunters enjoyed hunting rabbits and that provided protection for the rabbits through hunting seasons, banning the use of ferrets, and regulating the sale of rabbits that were taken legally.

In the past, the hunting seasons were designed around breeding seasons (Dambach 1948, Tober 1981). Conservation and sportsmen's organizations helped to shape the hunting seasons and the means of taking animals so as to ensure supply of game (Dunlap 1988). As far as transparency was concerned, changes in hunting seasons occurred often. In fact, it was difficult to determine or be in compliance with game seasons and shipment timing, as there was little transparency between states (Palmer and Oldys 1900).

All of these factors reflected the value of rabbits to citizens either for aesthetic reasons or for taking rabbits for their meat or fur. The first law to protect rabbits with a closed season (September 1 to February 1) was enacted in New Jersey in 1820 (Palmer 1912).

### *Regulating Hunting with Ferrets*

In addition to the controversial hunting of rabbits, the use of ferrets when hunting was specifically controversial. Some hunters thought it was easier to hunt rabbits with ferrets, since ferrets were efficient hunters, as long as the hunters were not bagging numerous rabbits at once with the ferrets (Recreation 1900).

On the other hand, there were many hunters who were opposed to allowing ferrets on hunts. For example, some sportsmen thought it was cruel to catch a rabbit with ferrets and wanted heavy fines placed on people who hunted rabbits with ferrets (Recreation 1900). This type of hunting was not easy on ferrets because sometimes hunters sewed the lips of the ferret (Wood 1865) and, if a muzzle was not put on the ferret, the ferret would not work well in a rabbit burrow (The National Encyclopaedia 1884). In addition, some people thought that hunting with a ferret was not sportsman like (Stonehenge 1859). Lastly, people were afraid rabbits would become "almost extinct" by hunting with ferrets in Ohio (The Stark County Democrat 1874). Lund (1980) suggested that legislators began to recognize that the take of game could be regulated by limiting the more efficient hunting methods, such as the use of ferrets for hunting rabbits (Linduska 1947).

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### *Regulating the Sale of Meat*

Selling leporid meat was also controversial for a variety of reasons. In addition to farmers, hunters also wanted to hunt rabbits and sell the meat. However, according to the Annual Report of the Game Commissioners of the State of Pennsylvania (1914), farmers did not have time to hunt and felt it was wrong for others to gain profit from meat taken from the farmer's land (Annual Report of the Game Commissioners of the State of Pennsylvania 1914). Additionally, people who enjoyed game meat would either need to become hunters or sacrifice eating game if meat selling was restricted (Michigan State Game, Fish, and Forest Fire Department 1889, American Gardening 1899). Some felt that if it was illegal to kill an animal out of hunting season, then it should be illegal to sell the animal outside of the hunting season (Palmer and Oldys 1901).

Lund (1980) suggested that the laws would be easier to administer when the crime was selling game rather than hunting it. Thus, ceasing to sell game was a way to protect leporids and prevented market hunters from illegal takings during a closed hunting season (Michigan State Game, Fish, and Forest Fire Department 1889). In fact, court proceedings dealt with the selling of game meat and ownership of game animals. One such case was the 1896 case of *Geer v. Connecticut*, which preceded the Lacey Act of 1900, and which stipulated that the state could regulate wildlife transport once the animal perished. The Lacey Act (1900) made it illegal to move killed wildlife into another state when state laws were violated (Lueck 1989).

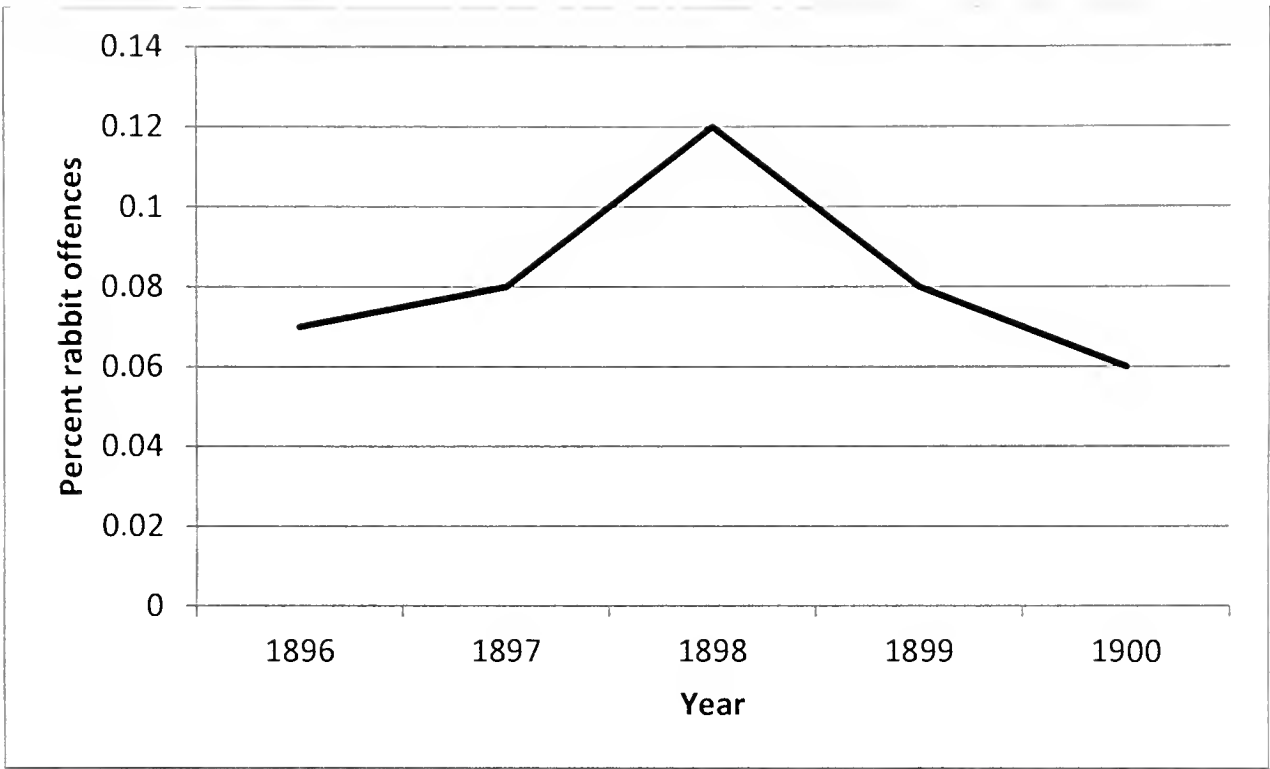
#### **One State Example: New Jersey**

This section describes one state and its prosecution data on violations that dealt with leporids. New Jersey was the first state to establish hunting season dates on rabbits in 1820. New Jersey utilized game wardens and sheriffs to enforce the game laws (see Annual Reports of the Board of Fish and Game Commissioners of the State of New Jersey 1896-1899).

According to New Jersey's 1896 Chapter 169, it was illegal to have a rabbit in possession except between the dates of November 10 and January 1. The fine was \$20 for each animal out of regulation. Figure 2 illustrates that during the first four years of this law, the highest instances of rabbit offenses occurred in 1898 in New Jersey (data obtained from Annual Reports of the Board of Fish and Game Commissioners of the State of New Jersey, 1896-1899). The offenses that occurred during the 4-



year period from 1896 to 1899 included killing, possession, snaring, snooding or netting, using a ferret, trapping, and offering leporids for sale (Annual Reports of the Board of Fish and Game Commissioners of the State of New Jersey 1896-1900).

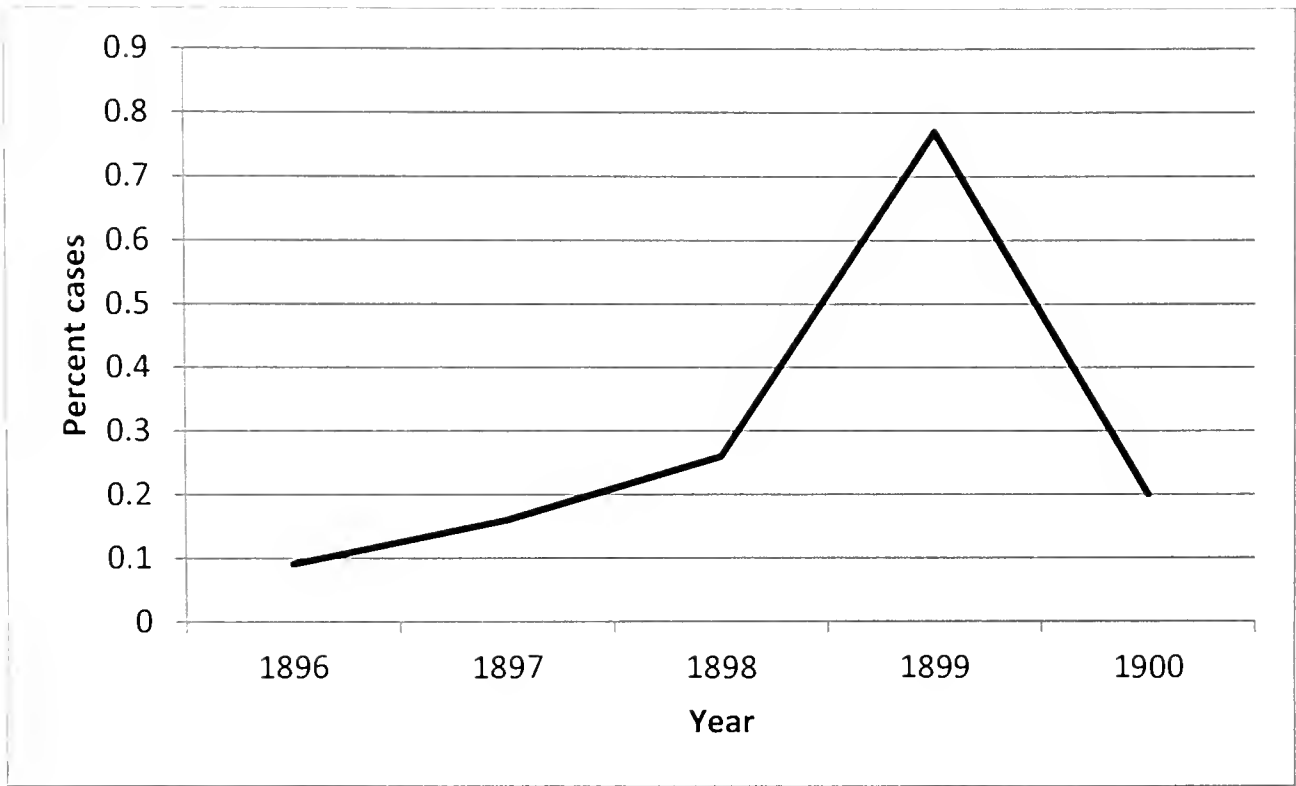


**Figure 2.** Offenses involving rabbits in New Jersey, 1896-1900

The year 1899 was the highest in terms of acquitted or suspended rabbit offense cases, with 77% of the cases being acquitted or suspended (Figure 3). By 1900, only 20% of the cases were acquitted or suspended (data obtained from Annual Reports of the Board of Fish and Game Commissioners of the State of New Jersey 1896-1899).

**Comparing Current and Historical Laws**

Current laws governing leporids retain many aspects of the historical laws, such as those regulating bag limits, hunting seasons, the sale of rabbit meat, rabbit coursing with dogs, use of ferrets in hunting, and banning hunting on Sundays. In the past, regulations regarding wildlife rehabilitation and more advanced transportation laws were not imposed. Hunting restrictions too, have evolved over the years (Lueck 1995). For example, it is unlawful to shoot from roads or hunt near buildings or machinery (see Lueck 1995 for more details). As for scalp laws, there are few to no leporid bounty regulations today.



**Figure 3.** Rabbit criminal cases that were acquitted or suspended in New Jersey, 1896-1900

Historical laws did not possess a species status classification system to specify which leporids were covered by legislation. Today, however, on a species level, one of the earliest leporids to be classified as “near threatened” status was the white-sided jackrabbit (*Lepus callotis*) in 1975 (IUCN 2013b). Leporids with threatened, vulnerable, and endangered species status include the Columbia basin pygmy rabbit, *Brachylagus idahoensis*, and the riparian brush rabbit, *Sylvilagus bachmani riparius*. For these species, the focus of leporid conservation has shifted to the restoration of habitats, translocation efforts, rehabilitation programs, recovery programs, and recovery plans.

Indeed, there are states where several species of leporids live and, in these states some leporid species can be hunted, whereas others cannot. For example, in Ohio the snowshoe hare (*Lepus americanus*) cannot be hunted, whereas other leporids *can* be hunted (Ohio Department of Natural Resources 2013). In addition, states such as Iowa and Missouri have banned hunting of white-tailed jackrabbits (*Lepus townsendii*) yet, in other states, the white-tailed jackrabbit can be hunted throughout the year.

Table 2 presents a synopsis comparing current and historic regulation related to leporids.

**Table 2.** Comparison of historic and current laws on leporids

| Historic Laws  | Current Laws  |
|--|---|
| Bag limits   | Bag limits continue   |
| Hunting seasons  | Hunting seasons continue  |
| Could not sell rabbits during off season in some states          | Cannot domesticate wildlife as pets at any time without an appropriate permit<br>Cannot sell wild game meat in some states  |
| Regulations on shipping rabbits to other states (1900 Lacey Act) | Transportation laws (1966 Animal Welfare Act and amendments) restrict shipping  |
| Could or could not use a ferret to hunt                          | Using a ferret to hunt rabbits remains illegal in many states   |
| Laws against rabbit coursing                                     | Rabbit coursing is illegal in some U.S. states, but remains legal in some   |
| Could not shoot on a Sunday                                      | Ban on Sunday hunting continues in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, North Carolina, Pennsylvania, South Carolina, Virginia, and West Virginia. (2008 State Sunday Hunting Ban Statutes) |
| Scalp/bounty laws  | None  |

**Summary of the Historical Underpinnings of Leporid Legislation**

Leporid legislation in the 19<sup>th</sup> century did not include regulations on disease, introduction of exotic species, or impact of fire or grazing animals on leporid populations. Instead, the historic laws related mostly to hunting seasons, with the first leporid season being established in New Jersey in 1820. This is consistent with Lund (1976) and Lueck (1989) who reported that the earliest state controls involved establishing hunting seasons. The first bag limit for leporids was in Wisconsin in 1903 (Palmer 1912).

Coggins and Evans (1982) noted that the laws were not consistent between states. For example, the eastern states focused on protection of leporids, whereas the western states imposed bounties. There are positives and negatives regarding the consistency among the laws. When laws *are* consistent within and between states, there is less confusion for hunters who travel between counties and states. However, when the laws are *not* consistent within and between states, it may lead to poor wildlife enforcement (Stockdale 1993). For this reason, laws may need to be inconsistent by necessity as habitat changes occur throughout regions and

related regulations on hunting may vary with regional wildlife and habitat changes (Lueck 1995).

As noted, certain historical laws and regulations have had a particular impact on the conservation of leporids today. They especially include regulations related to hunting and/or protection, the use of ferrets, and the sale of meat.

Regarding laws and regulations to hunt or protect, Lund (1976) suggested that the level of regulation was reliant on the degree of exploitation. This perspective could be hard to ascertain, given the lack of wildlife hunting statistics and population data for the 19<sup>th</sup> century. Today, population census records along with mortality and hunting statistics are used to help determine hunting seasons and bag limits.

Since hunting with ferrets was an efficient and effective means of hunting rabbits (Linduska 1947), some states banned using a ferret for hunting to protect rabbit populations (Dambach 1948, Quesenberry and Carpenter 2011). Ferrets are considered exotic animals, may become feral, and can prey upon native wildlife (Long 2003, Tully Jr. and Mitchell 2012). For these reasons, some states such as California do not allow ferrets as pets (Rollin and Kesel 1995). All of these factors may be reasons why ferrets are not used in hunting today to help conserve leporid populations.

Market hunting historically helped to supply meat and pelts to cities, but it has been suggested that the sale of wildlife meat may have led to declining wildlife populations (Geist 1985, Stockdale 1993). Regardless of whether the regulation of meat selling has contributed to wildlife conservation so that populations do not decline from market hunting, regulations on transporting or importing game meat are important so that diseases are not introduced or new species are not introduced that compete with native wildlife (Geist 1988, Butler et al. 2005).

### **Conclusions and Implications for Further Research**

Many aspects of the 19<sup>th</sup> century laws regarding leporids still exist today for the leporids that are allowed to be hunted in the United States. As discussed, this includes hunting seasons and bag limits, ferret restrictions, and meat sale regulations. Many laws in the 19<sup>th</sup> century did not specify which species of leporids were covered by legislation, as a species conservation status classification system did not exist in the 19<sup>th</sup> century.

The establishment of the hunting season was one of the earlier regulations for conserving wildlife in the United States, and hunting season dates and lengths were altered numerous times (Palmer and Oldys 1901). Presumably, a longer hunting season would decrease populations further than a shorter hunting season. However, it is unclear as to whether an extension of hunting season has an impact on overall wildlife population numbers. Palmer and Bennett (1963), George *et al.* (1980), and Rexstad (1992) found no effects of season length on population size or survival of various avifauna. However, Grau and Grau (1980) found that hunting season length was important and depended upon hunter effort, cost, management, and enforcement of laws as the hunting season lasted.

Similarly, few studies examine the length of the hunting season specifically on leporid population numbers. Regarding leporid hunting in the past, presumably a shorter hunting season meant less take; however, more data are needed to prove this. Dambach (1948) speculated that hunting season lengths for cottontails were dependent on hunting pressure, disease, or adverse climate in Ohio. Further research in this area could focus on how hunting season lengths have been chosen. As historical documents become more available, further research could also determine clear-cut dates as to when hunting allowed the use of ferrets in rabbit hunting in the United States.

Further research could focus on historical enforcement of the laws. Tober (1981) and Stockdale (1993) pointed out that laws were not enforced very well during the 19<sup>th</sup> century. It would be useful to note the number of wardens or officers available to catch violators, whether the wardens were paid or volunteers, how many violations were reported, and what crimes were reported more frequently – according to, for example, whether a warden or officer spent more time on land or water.

It would also be useful to compare additional state prosecution lists to determine how many violations involved leporids. This would enable a comparison of enforcement between states to determine if some states placed heavier emphasis on game or fish violations. If more emphasis was placed on game violations, this could reflect a rough estimate of wildlife abundance with regard to hunting (Dambach 1948) and could infer that leporid populations were healthier if there were fewer hunting violations.

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## **Bio**

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# Coiled Tubing Operations May Offer Paradigm Shift in Humanitarian Logistics

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## Abstract

TOHL, Tubing Operations for Humanitarian Logistics, is a start-up non-profit based on a logistical innovation responsible for the advent of mobile infrastructure. Using small-diameter flexible tubing, TOHL's goal of installing supply lines, particularly for water, quickly and cost-effectively is an important departure from the conventional methods of using disaster-affected roads and bridges for aid delivery. TOHL's founders recently demonstrated the concept by laying more than one kilometer of tubing in roughly nine minutes on July 5, 2012, in the mountainous fringes of Santiago, Chile. TOHL has created a potential paradigm shift in disaster logistics by aiming to provide water supply lines at an unparalleled rapid pace and with extensive operational versatility. The TOHL creators intend to use this advantage to change disaster logistics globally, one tubing operation at a time. This paper presents the decision-making and analyses involved in the process of exploring the technical feasibility and organizational sustainability of TOHL as a business venture.

## Introduction

**THE 2010 HAITI EARTHQUAKE**, with a catastrophic magnitude of 7.0 on the Richter scale, with an epicenter only 25 kilometers west of the Haitian capital, Port-Au-Prince, has been recognized as one of the largest modern devastations in human history. The tragedy claimed more than 220,000 lives and more than a million people were left homeless in its wake within a month of the earthquake (see Disasters Emergency Committee). The extent and magnitude of the devastation led to the commencement of one of the biggest modern relief efforts in recent history to aid Haitians with an influx of aid, money and relief workers from around the globe.

The disaster's scope served as the catalyst behind an innovation tailored specifically to resolve issues regarding the provision of water, the ultimate necessity for life, and its availability to disaster-affected victims. This new innovation, called Tubing Operations for Humanitarian Logistics, or TOHL, was conceived with the specific idea of helping

sustain human life post-disaster by providing supply lines for clean potable water to those in dire need of it.

Conception of the TOHL idea was the direct result of British Broadcasting Corporation (BBC) coverage of the Haiti disaster and its aftermath. The extensive media disclosure of the post-disaster relief effort was crucial in creating a catalyst for change in the minds of TOHL's founders – both engineering students at Georgia Institute of Technology (Georgia Tech) – and helping to identify that there was a problem amidst the broken infrastructure and shattered society of Port-Au-Prince. The founders of the non-profit TOHL, Inc. became convinced that the relief delivery systems used after disasters were not ideal, and that a better solution could not only help increase the rapidity and scale of help for disaster victims, but also be implemented cost-effectively.

The primary catalyst behind moving forward with the TOHL concept in its nascent stage was a dialogue that Bill Clinton, 42nd President of the United States and head of the post-earthquake operation in Haiti, had with the BBC. Among the various points Mr. Clinton raised with regard to the challenges faced by the relief workers, he emphasized an important fact that created clear validation for TOHL's founders that the field of disaster logistics was not in an ideal state. He highlighted that often it wasn't the availability of necessary resources on the ground that constrained relief operations, but rather the incapability of the local infrastructure to *deliver* the relief to the disaster victims. The BBC interview resonated instantly.

TOHL started from the outset as a brainstorming exercise about the most effective methods for transporting materials, and the possibility of creating post-disaster supply lines that could be installed rapidly.

TOHL was not conceived in a Georgia Tech classroom, although the conceiver, Sinha, the author of this article, was attending the university as a senior in Chemical Engineering at the time. TOHL was, however, the product of an iterative process by Sinha and his classmate — the TOHL organization's founding partner, Benjamin Cohen<sup>1</sup> — to improve on the initial concept and transform it into an economically feasible solution to problems in providing disaster relief. The original inspiration to resolve the problem of disaster logistics emerged from Sinha's experience as an oil field intern in the summer of 2009. He discussed his initial concept at great length with Dr. Matthew Realff, associate professor at the Georgia Tech School of Chemical and Bio-molecular Engineering at the time. TOHL's co-founder, Cohen, joined the team promptly thereafter.

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## Conventional Humanitarian Logistics

In the immediate aftermath of the Haiti disaster, the small team that TOHL comprised — Sinha, Cohen, and Dr. Realff — investigated the contemporary state of humanitarian logistics. They found that existing disaster relief operations throughout the world use the remnants of the pre-disaster local infrastructure to create logistical supply lines to aid victims.

As such, the ability of the pre-disaster local infrastructure to withstand a disaster is an important factor in determining the rapidity of post-disaster operations. This fact has important repercussions for any disaster relief system already in place or being developed. For example, if *all* the local roads and bridges have been rendered useless by a natural calamity like an earthquake, relief organizations would be much slower in commencing operations than in a scenario where only a *portion* of the roads and bridges are damaged.

The impact of disasters on the local infrastructure can vary in both magnitude and profile. The randomness of damage inflicted is a primary reason behind the need to customize every response situation. The uncertainty associated with disasters mandates a rapid response and strategic shifts in the logistics of every operation, thereby reducing efficiency in the rate and volume of delivery.

It would also stand to reason that the scale of a post-disaster operation would be a function of the number of victims affected in a region. Presumably the relationship would be direct — that is, more money, personnel and time would be allocated to affected areas with larger populations than those with smaller populations. In the field of humanitarian relief, the needs of the many almost always outweigh the needs of the few, and for good reason.

However, in humanitarian logistics (a subset of humanitarian relief operations), the TOHL group found that the efficiency of an operation has no correlation with the number of affected victims. A humanitarian logistics operation might be effective at providing aid to a hundred people, yet completely helpless in delivering aid to hundreds of thousands of people due to logistical bottlenecks and a lack of post-disaster infrastructure. Put simply, the efficiency of a humanitarian logistics operation does *not* have a direct relationship with the number of affected people. A high number of disaster victims does not necessarily mean aid will be delivered more quickly or efficiently to them than to smaller

pockets of victims — even if the efforts, personnel and time attributed to the project have been scaled as necessary.

### **Ideal Humanitarian Relief versus Logistical Trade-offs**

In an ideal world, a logistician working for a disaster relief agency or a government emergency response branch would be able to reach and deliver aid to the largest number of disaster victims in the shortest amount of time, throughout the affected region without any restrictions. The food, water and medicine stocked in government or non-governmental organization inventories would be moved out of the warehouses as soon as they are received and begin their journey toward disaster victims. The stocked aid would be dispersed in a way to maximize the number of people helped in the least amount of time possible to prevent the loss of life due to starvation or lack of water. The ideal relief effort would also maximize outreach to the various geographic parts of an affected region. The logistician's only consideration would be the anticipated demand for aid in a particular region, and not the limitations of the crew in delivering the aid. Ideally, the logistician would not consider anything but the needs of the disaster victims in determining the flow of aid. Also, the logistician would have a complete range of movement throughout an area when choosing the optimum course of action. The issues presented by faulty or non-existent infrastructure would be circumvented in an ideal relief operation. Most importantly, the favorite humanitarian logistics operation would be cost-effective and, ideally, free of cost.

The above ideal scenario for a disaster logistician is considerably different from an actual situation witnessed on the ground. In reality, an approach that balances versatility and performance with cost-effectiveness is still missing.

### ***Historical Use of Aerial Vehicles and Modern-Day Costs***

While the local infrastructure and its post-disaster condition can hamper the effectiveness of relief operations using land vehicles, the strategic use of aerial vehicles like planes and helicopters could help to overcome these restrictions.

The battle for Britain was won, among other reasons, due to the Allies' airlifts that helped sustain the British population (Wilmot, 1997). The Russians survived Germany's invasion due to a similar effort by the Allies who used parachute-dropped supplies to sustain the Russian troops

and general populace (Wilmot, 1997). While the glorified efforts of the Royal Air Force and the well-documented Russian policy of “scorch and burn” have been established rightly as the key factors in these battles, the air-drops of aid served as important contributors to the outcomes of the two conflicts.

Like war, post-disaster logistics is more of an art than a science. The money spent on using aerial methods in the rather unglamorous field of humanitarian logistics presents a serious issue for logisticians. Money is the most liquid asset available to relief logisticians. The prudent use of money is crucial to maximizing the number of lives saved after a disaster. Aerial methods are considerably more expensive than land-based logistics operations. Due to these inherent costs, aerial vehicles are seldom used for relief delivery operations — and are actually used only as a last resort. The logistician is forced to examine the use of aerial delivery with extreme scrutiny because its trade-off value is particularly high. With a cost of roughly 30 to 80 times higher than the use of land transport in most post-disaster situations, the use of helicopters is abandoned for cheaper alternatives.

Based on typical disaster conditions and scenarios, pockets of disasters victims may be left without access to external aid for long durations of time. Instead of choosing an expensive method to reach them, the choice may be made to wait until the repair of the local infrastructure before a substantial influx of external aid can commence.

### **Paradigm Shift**

With the above situation predominant in the field of disaster logistics today, Sinha and Dr. Realff initially discussed the prospect of change. They analyzed the notion of creating *new* supply lines after a disaster, rather than focusing on improving the rate of infrastructure repair. New supply lines, functioning as an infrastructure independent of the local roads and bridges, could prove useful in maximizing the reach of logisticians in disaster-affected regions.

However, the new supply lines would need to meet other criteria, as well. In order to make any difference in the field of disaster logistics, they would need to have the potential of rapid deployment — at least quicker than the time required to repair the pre-existing infrastructure. They would also need to offer other benefits over infrastructure repair, such as versatility in application and the ability to be deployed in a variety of disaster scenarios with ease. They would also need to be scalable with

both the flow of resources that could be managed, as well as the distances that could be traversed. Most importantly, they would need to be cheaper than the use of aerial methods — in fact, much cheaper initially to convince logisticians to use them in place of other existing approaches.

As TOHL began taking its first steps towards viewing disaster logistics through a new paradigm, Dr. Realff provided an important piece of advice. Based on the radii of downtown sections of the world's major cities, he proposed that any supply lines that could cost-effectively and rapidly create a flow of resources such as water over a distance of 10 kilometers or more — and could do so for many types of disasters with relative ease — would be valuable to a logistician. Such a system, the newly-formed TOHL team agreed, would have the potential to replace current practices in the disaster logistics industry.

The traditional approach of using the pre-existing infrastructure to carry out relief efforts could potentially be replaced with an innovative stance of creating a rapidly deployable mobile infrastructure. In theory, the mobile infrastructure could be slotted in place during the first stage of a disaster response, and then removed once the pre-existing infrastructure was rebuilt. Once installed, such supply lines would not only help increase the range of a relief delivery effort in its first stage of response, but would also disengage the repair of the local infrastructure from the relief effort.

Based on this line of thinking, the questions then became: What would constitute this mobile infrastructure? What would the supply lines be? How could they be deployed quickly, and over a variety of terrain? How could they be cost-effective and also have the potential to scale, per the needs of the situation?

### **Coiled Tubing**

Answers to the above questions were found in the oil field. Sinha had worked through the summer of 2009 in Middle Eastern oil fields. He proposed the use of homogenous tubing, such as that used in well services around the world, as a possible method of creating the desired mobile infrastructure.

#### ***Historical Use of Coiled Tubing in Wartime***

The earliest use of coiled tubing dates back to the second World War, when the Allies used a similar method to create fuel supply lines to facilitate the invasion of the Normandy beaches in the decisive battle that started on D-Day (Searle, 2004). The project was named by the acronym



“PLUTO,” which stood for Pipelines Under The Ocean. Spooled tubing was laid across the English Channel. It was designed to be denser than water so as to be concealed from view. A set of about twenty independent tubing systems was installed for this purpose and was a crucial component of the D-day invasion. The tubing was also designed to have a small diameter. This not only decreased the installation time, but also served as a safety measure since a leak in any one tube would not hamper the fuel rate drastically.

### ***Recent Applications of Coiled Tubing in Oil Fields***

After its debut, coiled tubing regained prominence in oil field use following a hiatus of more than 30 years. A problem faced in the adaptation of coiled tubing for down-hole oil field operations was that the tubing, which was used as an interface between the high down-hole pressures and the low pressures on the ground, would snap out of the wells and create damage. This issue initially stalled use of coiled tubing in well-service applications. However, the creation of high-pressure injectors in the 1980s allowed the safe insertion of coiled tubing into high-pressure wells. Coiled tubing offered well-service companies an efficient way to lower tools and sensors down into the well hole. It also served as a useful supply line for tools and liquid acid over tens of thousands of feet, and could be deployed in a matter of hours to accommodate high flow rates during operation. It offered well-service companies an efficient method to target particular zones in the well bore for stimulation operations. Through the use of coiled tubing, the operator could accurately target specific depths for acidization, and thereby minimize the loss of acid volume to neighboring zones. Most importantly, coiled tubing worked independently and did not require any support of the well bore casing or liners during deployment. All of these attributes have made coiled tubing an integral part of oil field well-service operations.

Based on these attributes, the TOHL founders become increasingly confident that the flexibility and strength of coiled tubing would offer an advantageous addition to the arsenal of disaster relief logisticians. Since coiled tubing’s first application was in logistics, they feel the technology’s story is coming full circle with the founding of TOHL Inc.

### **Demonstrating Coiled Tubing Operations**

The TOHL team’s first job was to adapt and test the oil field application of coiled tubing for a new incarnation in the field of disaster logistics. The new tubing concept and unfolding TOHL organization

entailed new activities and required more staff to help with those activities.

Based on Dr. Realff's early counsel (to focus on enabling water flow over a distance of 10 km), the team became convinced that the use of light, flexible, quickly-deployable, small-diameter tubing would work to create a mobile infrastructure faster than pre-disaster infrastructure could be restored to functionality. For humanitarian operations, the TOHL tubing would be constructed out of high-density polyethylene (HDPE)<sup>2</sup> tubing, a material that has been certified by the U.S. Food and Drug Administration (and similar regulatory agencies in other countries) to carry potable water. HDPE has been tested successfully to work at a temperature range of 60 degrees Celsius to -30 degrees Celsius without any lasting deformation or other issues.

As the concept grew, the TOHL team also grew steadily through the addition of motivated Georgia Tech graduates. For example, Melissa McCoy<sup>3</sup> and Travis Horsley<sup>4</sup> were instrumental in creating the first source of funding for the budding TOHL start-up via the Start-Up Chile program.

Relocating to South America, Cohen and Horsley were able to use their new, but limited, funding judiciously to test the viability of the mobile infrastructure through a pilot run. TOHL's first pilot run took place on July 5, 2012, a windy day in the hilly outskirts of Santiago, Chile. For this full-scale test, a helicopter with a load capacity of 1,500 pounds carried roughly 1 kilometer of small-diameter HDPE tubing and quickly laid a supply line through a path bursting with cacti in less than 9 minutes! (see Figure 1)

This fast 9-minute test run helped to show that mobile infrastructure would outpace almost any effort to repair damaged local road infrastructure. It also showed that the concept could transcend the likely trade-offs and challenges (such as, for example, cacti and brush) that might hamper the use of conventional infrastructure.

### **Benefits of Tubing Operations for Humanitarian Logistics**

We believe that mobile infrastructure offers several advantages over conventional infrastructure in post-disaster relief situations. The benefits primarily relate to: (1) response time and delivery optimization; (2) the advantage of continuous delivery; and (3) more effective use of relief personnel.



**Figure 1.** Proof-of-concept test in the mountains of Chile.

The location of roads and bridges is fixed and cannot be altered. If a disaster were to force victims to find refuge away from the existing roads, their migration — however small in distance — would drastically increase the time and effort necessary to deliver aid. During the first stages of disaster response, time is the most crucial commodity and is highly correlated with the number of lives saved. Mobile infrastructure offers the potential to lay supply lines to reach inaccessible disaster victims quickly and to target the exact location of victims — thereby increasing the likelihood of optimally delivering a larger amount of external aid to more locations in a fixed period of time.

TOHL supply lines also offer another fundamental advantage over the use of conventional or permanent infrastructure. They are inherently continuous in nature, as opposed to the supply lines established by vehicle transportation. The use of land or aerial vehicles requires a routine return to a base location to ensure a constant flow of aid.

The use of conventional vehicles requires the engagement of equipped personnel who are almost always in dire supply. This need for personnel usually outlasts the local infrastructure repair process, as community rebuilding is a long-term process. It requires constant supervision by logisticians in charge to ensure that operations are running smoothly. In contrast, the use of TOHL tubing could create a supply line system similar to existing plumbing systems evident in some developed countries; once installed, and with the security aspects in place, it is likely that a TOHL system would not entail the need for constant monitoring, barring some contingency event. This would allow a logistician to better manage the limited time availability of relief operation personnel who are needed for multiple purposes.

### **Water Delivery: Steps to Become Operational**

The TOHL developers identified water as the most important necessity for disaster victims, for readily apparent reasons. While the average individual has the capability to survive without food for perhaps two weeks, the same person would struggle to endure two days without water. It was clear to the TOHL founders that a rapid way of delivering water to disaster victims is crucial to the success of any humanitarian logistics operation.

For water delivery, the TOHL tubing would convert the conventional batch process of delivering bottled water with a continuous water delivery system. It is projected that the TOHL method for water

delivery would be more cost-effective, energy-efficient, and environmentally-friendly than conventional methods of going back and forth, once the operational stage is reached. Getting to that stage will involve: (1) identifying available local water sources; and (2) converting the water to potable water for consumption by victims.

In situations where the TOHL package is used to deliver water, local sources of water must be found, investigated, and approved in order to source the local water for victims. From TOHL's experience in Chile, local sub-surface aquifers are the most common and reachable sources of potable water for use in TOHL operations. At other locations, water could be sourced from surrounding on-surface bodies of water such as seas, lakes, and oceans, depending on their availability.

The water from the source location must be transformed into potable water before it is pumped through the TOHL system and transported to target locations. In order to meet water purification needs, TOHL has developed partnerships with certain water purification companies to ensure that TOHL's water sources can be made potable. TOHL has collaborated with two partners who hold U.S. patents on their water purification technologies. They also exhibit the ability to scale up in purification volume, and have been tested by independent third parties for performance review. These partners are Innovative Water Technologies and a company in Chile that has patented a plasma-based water purification system.

TOHL has aggressively explored the use of solar power to both drive water through the tubing system and purify the water. Based on the particular situation evident in a disaster relief assignment, the pumps providing the driving force for TOHL's logistics could actually be powered using multiple sources. Most commercial motor assemblies that power pumps operate using diesel, petroleum, or natural gas as the fuel. If provisions need to be established for these fuels, TOHL lines could also be used to carry the fuel from an airport or seaport to the source of the water for the TOHL water lines. The TOHL lines carrying the fuel would normally be rated for higher pressures and evaluated per more stringent performance criteria to ensure safe transport of the fuel.

### **Model for Working with Local Clients**

To fulfill its business plan, the TOHL enterprise is working aggressively to accumulate a global network of local clients, and has developed a model for working with those clients. Once a TOHL package

has been supplied to a local client, the most sustainable way to incorporate it into the framework of tools used by local logisticians is by: (1) training the local workforce of logisticians; and (2) providing an option for maintenance and consulting if/when required in the future.

Training the workforces of TOHL's clients will allow those clients to integrate the TOHL package seamlessly into their pre-established logistical framework and optimize the TOHL application for local use. This would necessitate, for example, identifying a local power source for driving the system pumps. TOHL management believes that empowering clients with ownership of the package will allow the speediest response in the event of a disaster.

There is also the option of having the TOHL management team available on-site to assist with a disaster response. During the later tubing removal stage, TOHL can provide assistance, although the earlier training stage should help ensure the user will be sufficiently capable of carrying out this operation independently.

### **Addressing Risks and Uncertainties**

Disasters, natural or human-caused, are clouded by uncertainty, regardless of the methods used for disaster relief. Disaster logistics is, by nature, an inexact discipline because it depends largely on the post-disaster state of the local infrastructure — and this varies, based on not only its pre-disaster condition, but also the extent and type of the disaster. For this reason, every operation must be considered in isolation, and every solution must be tailor-made to suit the situation being tackled. There are levels of uncertainties associated with almost every factor of a relief operation, from equipment needs and security concerns to local geography.

### ***Preparing for Equipment Needs***

The TOHL group has developed a network of service providers and suppliers in North America and Chile for the necessary helicopters, tubing, and pumps. The above model for working with local clients is intended to help establish an even broader network throughout the world. As noted, subject to client needs and the local availability of energy, the pumps that are used could be powered by diesel, natural gas, wind or solar power. The local availability of parts required for a TOHL operation can play a role in determining the feasibility of an operation and its associated costs. Some cost uncertainties can be overcome by basing cost estimates

on the industry standards for necessary items such as, for example, pump specifications and pressure ratings.

### *Tubing System Security*

System security is an important factor in humanitarian relief. With other types of operations and applications (such as oil and gas), the tubing would typically be installed on land owned by known entities, making the possibility for vandalism less likely. We assume that security provisions for a hypothetical TOHL operation on privately-owned land should be similarly easy to establish. In the field of humanitarian logistics, however, the issue of security could be a factor as disaster victims who are battling the disaster conditions, possible starvation, and each other may be prone to causing infrastructure damage for their own gains. TOHL has devised three methods to mitigate the security issue, as described below.

Where possible, it is recommended that, post-installation, the tubing be buried several feet underground. HDPE tubing has historically shown positive results under the pressure of soil resting on it. Extensive tests to verify this were conducted by the Plastics Pipe Institute in collaboration with the U.S. Department of Agriculture, with positive results. This signifies that TOHL tubing used in humanitarian logistics could be buried.<sup>5</sup> Doing so would add a physical layer of protection and make vandalism more difficult. It would also help to stabilize the tubing and ensure that environmental conditions do not rupture it or interfere with the continuous flow of supplies.

TOHL management has learned that, in a humanitarian crisis zone, the single most important factor in ensuring the security of the equipment and crew is the relief organization's relationship with the local community leaders. Therefore, a second strategy for mitigating the potential problem of vandalism is to acquire the approval of the local leaders for the supply line. This will help ensure that the community will take ownership of the physical infrastructure and equipment, once installed and operational.

TOHL's management also explored security strategies with the widely-known behavioral economist, Dan Ariely, and his research group. The author of the best-seller, *Predictably Irrational* (2008), Ariely advocates the use of empirically-found truths of human behavior to solve societal problems. His research associate, Jamie Foehl, assisted the TOHL team in devising several additional security mitigation strategies. One such strategy would be to reduce the supply flow rate in the event of a tube rupture, and make sure that the local public is well informed in advance of



the consequences of such an action. Another mitigation measure would be to place markers that show the distance to the target location along the length of any unburied tubing. This would help assure people that they are not far from the end of the tubing line and can soon reach the location for access to supplies without having to take drastic negative action before then.

### **Cost Estimates and Comparisons**

The cost parameters associated with a disaster logistics operation are a major consideration in any scenario. Since TOHL conception, the founders have spent a considerable portion of their time examining the costs of implementing a TOHL operation, and verifying its ability to compete with conventional logistics from an economic standpoint.

The team established a heuristic for the operational results of installing 1 kilometer (or 0.6 miles) of small-pressure tubing (with a rating of roughly 250 pounds per square inch) based on several terrain scenarios, as follows:

**Case 1:** Installing 1 km of tubing over difficult terrain but with no height change, the flow rate delivered from the source location to a target location is estimated to be 300 liters per minute or more. In this scenario, the achieved flow rate could conservatively support over 300,000 people a day (assuming ~1.5 liters per person per day).

**Case 2:** A positive elevation change of approximately 30 meters from the source to target would deliver a reduced flow rate of about 8 liters per minute. In this scenario, we estimate that the flow rate could support approximately 7,500 people a day.

As is evident from the flow rates in cases 1 and 2, if the height difference between the source and target locations were reduced, the delivery rate could increase exponentially.

In the above cases, the cost of a TOHL team installing 1 kilometer of tubing using a helicopter would be consistent. Based on the pilot run in Chile in July 2012, 1 kilometer of tubing with the above parameters can be installed via helicopter in less than half an hour, even in aggressive ambient conditions such as strong winds and difficult terrain. The installation cost would include, conservatively, the labor and helicopter operation cost for a 2-hour period. Based on Chilean local rates, the cost of the labor and helicopter to deploy TOHL tubing over 1 kilometer was



less than \$3,000 (USD). Accounting for the cost of deploying the pumps, connecting the tubing system to the power source and making the TOHL line fully operational, the total installation cost for the TOHL operations described in cases 1 and 2 would amount to \$4,500 (USD) based on our pilot study results.

While the operational cost of a TOHL system is simply the cost of the fuel needed to run the system after installation, conventional batch methods require regular returns of the vessels carrying supplies (i.e., trucks or helicopters) to the target locations. Assuming an hourly rate of \$1,000 (USD) and \$40 (USD) for the use of a helicopter and truck respectively, inclusive of the labor cost, a TOHL system is found to be cost-effective relative to helicopter use within 2 weeks, and cost-competitive relative to truck logistics within a month of operation in both cases 1 and 2. This analysis assumes the helicopter is run for 6 hours per week to meet the required flow rates, and a truck caravan is run for roughly 50 hours per week to meet the same demand. It is important to note here again that in post-disaster situations, the functional roads are usually very congested and land-based vehicles suffer from severe bottlenecks.

### ***Comparing TOHL Estimates with Conventional Methods***

The TOHL cost estimate can also be compared with the estimated costs of conventional methods of disaster logistics when a particular timeline is established for the analysis.

For this purpose, TOHL's management communicated with disaster operation managers for various humanitarian organizations that were active in Haiti after the 2010 earthquake. They learned about the conditions that existed in the immediate aftermath of the quake, including: the ground situation; the distances between the Haitian airport in Port-Au-Prince and the key relief camps; and, the height differences between the airport and those locations. Given the existing parameters, they made the following estimates:

- We project it would have taken a TOHL team less than 48 hours after the required equipment arrived at the airport to have installed a 7-kilometer (approximately 4.3-mile) tubing system to a major victims' camp outside of Santiago.

- The tubing could have provided water at volumes of 500 liters per minute.<sup>6</sup> It is estimated that this would support a population of more than 450,000 with their water needs.
- The cost for such an operation is estimated to be approximately \$150,000, inclusive of the installation cost, water treatment provisions, and pump and motor assemblies.

It turns out that actual figures incurred for the conventional logistics used at the time are not available for comparison purposes. However, it is important to note that a response time of 48 hours to provide potable water was not even possible with conventional methods, given the tools that were available there at the time. In parts of Port-Au-Prince and Haiti, the time required for infrastructure repair was more than 60 days, which denied the logisticians a cost-effective method to deliver aid to the inhabitants. For particular densely-populated population centers in the vicinity of Port-Au-Prince, TOHL lines could have established a reliable supply of potable water within 72 hours of the necessary equipment reaching the Port-Au-Prince airport, the only functional international airport in the country in the immediate aftermath of the earthquake.

In summary, these early economic analyses reveal several general findings at this point about the use of mobile infrastructure in disaster relief. Mobile infrastructure appears to be a practical alternative to the restoration of permanent infrastructure. It may offer a cost-effective option relative to the use of aerial vehicles dropping in supplies and other resources. And, from an operational standpoint, it is definitely competitive with the use of land vehicles for delivering the same aid in most contemporary scenarios evident globally.

### **Conclusion**

The TOHL concept is the result of an unfolding paradigm shift aimed at tackling existing trade-offs facing the field of disaster logistics. Instead of looking at ways to repair conventional permanent infrastructure, the TOHL group is devising a method for deploying mobile infrastructure. Such a method could provide a logistician with versatility and flexibility in operations through continuous supply lines for delivering resources needed immediately after a disaster.

Application of the TOHL concept to disaster logistics centers primarily on exploiting the ability to deploy rapidly in isolated regions or

areas where the existing infrastructure cannot support the delivery of relief. TOHL's supply lines could be deployed initially using aerial vehicles. This would provide the ability to deliver aid thereafter without the later need for aerial vehicles.

Based on economic analyses conducted by the TOHL founders, the installation of mobile infrastructure offers not only a practical alternative to the restoration of permanent infrastructure, but also a cost-effective option relative to the use of aerial vehicles dropping in supplies and other resources. From an operational standpoint, mobile infrastructure is competitive with the use of land vehicles for delivering the same aid.

In the laying of a supply line in the mountains of Chile, the new TOHL enterprise demonstrated that a new tool can be added to the arsenal of disaster logisticians. Since the successful proof of concept in July 2012, the TOHL team has been constantly working toward applying the idea of using coiled tubing toward modern-day humanitarian relief.

The use of tubing proved crucial in the decisive battle of the Second World War. Those who valued human freedom and choice defeated those who did not in World War II, and an important step was taken at that time toward a more ideal world. The TOHL concept of today may also be a step in the right direction for the fields of disaster logistics and humanitarian relief – toward more ideal methods for logisticians attempting to improve their provision of post-disaster relief.

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<sup>1</sup> Benjamin Cohen is the co-founder of TOHL, Inc. and currently serves as its President and CEO. A Civil Engineering graduate from Georgia Tech, he has spearheaded TOHL's emergence as a business and has been responsible for the creation of the start-up's base of operations in Santiago, Chile. Mr. Cohen is also an Echoing Green Fellow, 2013.

<sup>2</sup> HDPE (High-Density Polyethylene) is a dense form of one of the major plastic materials used in plumbing and agricultural applications. HDPE offers robust performance over temperature variations and has been approved by many organizations worldwide to carry potable water safely. HDPE also offers the advantages of light-weight and low-to-medium pressure ratings that can allow significant water flow rates during operation. HDPE has a proven lifetime of up to 40 years and can be installed multiple times without showing any signs of fatigue. This compares favorably against the fatigue evident in stainless steel tubing after multiple coiling and uncoiling cycles.

<sup>3</sup> Melissa McCoy serves as an advisor for TOHL. She joined the team in August 2011 and worked on the ground in Chile in September 2012. Her engineering education, work experience, Spanish fluency, and expanded network has allowed her to contribute to TOHL on both technical and business issues, and she now focuses on operations and external relations tasks of the venture.

<sup>4</sup> Travis Horsley is a partner of TOHL. Travis is part of the original TOHL team, and was instrumental in the strategic partnerships in Atlanta and Santiago to move the company from a tested technology to a scalable solution for fluid transportation for industry and humanitarian logistics. Travis manages promotion in local and international media, gauging new strategic markets for product entry, and seeking investment via business incubators and angel networks.

<sup>5</sup> Burial may be more feasible in the event of certain types of disasters more than others, as it is unlikely the tubing could be buried cost-effectively if it is laying on a pile of rubble created by an earthquake. Also, if a line were to be buried in the wrong place, it's possible that a flood could wash it out.

<sup>6</sup> It is conceivable that the tubing could also have delivered granular food or small medical supplies. The use of TOHL tubing to deliver solid packages has not been tested, but TOHL's management team states the tubing has the capability to deliver fluids and solids through an inner diameter of more than 10 centimeters. They anticipate this may be sufficient to handle more than 95% of the immediate requirements in a first-stage disaster response operation. Solid packages would be easier to transport as individual packages, and could be strung together through plastic welds to create a continuous transfer of material through the supply lines. The non-food materials required in the first stage of a disaster response are usually small medical supplies such as pills and needles.

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## Bio

**Apoorva Sinha** is the conceiver and co-founder of TOHL, Inc. and currently serves as its Vice-President of Research & Development. A Chemical Engineering graduate from Georgia Tech, Mr. Sinha is currently pursuing a Master's in Chemical Engineering at the University of Calgary, and is very interested in innovation. He is responsible for providing leadership in creating new avenues for the expansion of TOHL's applications into new industries, particularly the oil and gas and marine salvage industries, among others.





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## Journal of the Washington Academy of Sciences

**Editor** Sally A. Rood, PhD [sally.rood2@gmail.com](mailto:sally.rood2@gmail.com)

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## Editor's Comments

The articles in this issue reflect two particular interests of the Washington Academy of Sciences: (1) space programs/ astronomy, and (2) research related to the environment.

### Space Programs and Astronomy

The first article, **“Humans to Mars: Stay Longer, Go Sooner, Prepare Now,”** reflects the passions of the author — Douglas Gage, a former DARPA program manager — on sending humans to Mars. The article discusses the private and NASA roles required to do this.

The second article, **“A Brief History of Government Policies to Promote Commercial Space”** by Bhavya Lal, discusses the history of both private and government support of private sector activities in the United States for promoting the commercial space sector. Lessons can be drawn from attempts by U.S. agencies to support this sector according to the paper — part of a study for the White House Office of Science and Technology Policy.

[Commercial time out: Given our space/astronomy theme here, I'm taking this opportunity to “plug” the Academy's most recent monograph, *A Century of Astronomy from the Journal of the Washington Academy of Sciences* (August 2012), available through [Amazon.com](http://Amazon.com)!]

### Research Related to the Environment

Our third article of this issue is on **“Estimating the Climate Impact of Transportation Fuels”** — and is especially relevant because it highlights the timely example of *biofuels* to illustrate the usefulness of a new analytical application called Integrated Modeling Systems Scenario Analysis. The author, Mark Delucchi, is developing this approach at the University of California-Davis Institute of Transportation Studies.

### Academy Activities

This Fall's issue is rounded out with the fascinating and entertaining speech by author Sam Kean at the Washington Academy of Sciences annual awards banquet in October 2013. Also featured is a photo montage of the program and awards ceremony, and a listing of this year's awardees and their fields.

We include here, regretfully, a notice of the passing of Cliff

Lanham, a Washington Academy of Sciences member for many years and delegate representing the Washington Area Chapter of the Technology Transfer Society.

Before closing, I'd like to acknowledge the local role of Kaye Breen, President and CEO of the nonprofit Ballston Science and Technology Alliance (BSTA), in identifying Washington, D.C. area experts in many fields of research who continue to enthrall the public in our region through BSTA's Café Scientifique.

Lastly, please note this new email address for communicating regarding *Journal* content: [sally.rood2@gmail.com](mailto:sally.rood2@gmail.com)

Sally A. Rood, PhD, Editor  
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# **Humans to Mars: Stay Longer, Go Sooner, Prepare Now**

**Douglas W. Gage**

**XPM Technologies, Arlington, Virginia**

## **Abstract**

Mars is the appropriate next destination for humans in space (not the Moon or an asteroid). Our initial program should send only two 6-person crews to Mars, and they should each remain on the surface for 8 years (as opposed to 5 crews, each for 18 months). The key challenges to the success of the Mars enterprise relate to the surface stay (as opposed to the travel to and from Mars). These challenges will be most effectively and efficiently addressed with long-term low-level efforts which: will involve many disciplines; should involve many organizations; and should be initiated now. NASA's unique skills and experience should be applied immediately to answer several specific critical questions.

## **Introduction**

**WHILE THE MARTIAN ENVIRONMENT** is extremely harsh to human sensibilities, the planet Mars is far and away the single best choice for an initial extended human presence beyond Low Earth Orbit (LEO). Balancing the difficulty of getting there, the resources available there, the challenges of keeping people alive there, and the probable payoffs of exploring there, no other extraterrestrial destination can compete (see Appendix B). If we can't demonstrate that humans can live on Mars, then we as a species aren't going anywhere else beyond Earth; moreover, if we do in fact demonstrate how humans can successfully live on Mars, we can fruitfully apply some of the lessons we learn doing this to the challenges we face living on Earth. While science fiction has treated the planet Mars as its number one destination in space for over a century [1], actual space exploration efforts are only now becoming seriously focused on sending humans to Mars.

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This paper was first presented at the June 4, 2013 Café Scientifique sponsored by the Ballston Science and Technology Alliance, [www.arlingtonvirginiausa.com/bsta](http://www.arlingtonvirginiausa.com/bsta), Kaye Breen, President & CEO.

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## The Planet Mars

Facts and figures about Mars are available from numerous print and web resources, including Wikipedia, and many images are available on the websites of specific missions, such as the Mars Reconnaissance Orbiter (MRO) or Mars Science Laboratory (MSL) Curiosity. Individual reference citations have not been included in this paper for each individual mission or for every scientific term for which Wikipedia provides good introductory information and/or the obvious web search will lead to an appropriate website. Physical values presented here should be treated as close approximations — for example, equatorial diameter is slightly larger than polar diameter, atmospheric pressure changes daily and with the seasons, and Curiosity's reports of atmospheric composition differ from those returned by Viking [2].

Mars is a small planet, whose diameter of 6,779 km is just over half of Earth's 12,756 km. As a result, gravity at the surface of Mars is just 37.6% of Earth's ( $3.7 \text{ m/s}^2$ , compared to Earth's  $9.8 \text{ m/s}^2$  and our Moon's  $1.6 \text{ m/s}^2$ ). The Martian day ("sol") is 24 hours and 39 minutes long, remarkably close to Earth's 24 hours. The Martian year is 687 Earth days, or 668 Martian sols.

Mars' orbit deviates significantly from circular, ranging between 206.6 and 249.2 million km from the Sun (compared to a near-circular 149.6 million km orbit for Earth), and Martian seasons are therefore not equal in length. Mars is closest to Earth when Earth is directly between it and the Sun (Earth-based astronomers call this "opposition," since Mars and the Sun are opposite in the Earth's sky) — between 57.0 and 99.6 million km, depending on Mars's distance from the Sun at this point.

Conversely, Mars is most distant when the Sun is directly between Earth and Mars (Earth-based astronomers call this "conjunction," since Mars and the Sun appear to be very close in the Earth's sky) — between 356.2 and 398.8 million km. Round trip light or radio communication between Earth and Mars therefore takes between 6.3 and 11.1 minutes at opposition, and between 39.6 and 44.3 minutes at conjunction. The synodic period, the time from one opposition to the next, or from one conjunction to the next, is about 26 months (780 days).

Mars receives an average insolation of  $580 \text{ w/m}^2$ , about 43% of that received on Earth ( $1,360 \text{ w/m}^2$ ). Temperatures on the surface of Mars average  $-63^\circ\text{C}$ , ranging from  $+32^\circ\text{C}$  to  $-140^\circ\text{C}$ . Southern winter is much more severe than northern, to the point that enough atmospheric  $\text{CO}_2$  freezes out

onto the south polar cap to reduce the atmospheric pressure across the whole planet by about 30%. The planet's tilt, or obliquity, is about 25.2 degrees, remarkably close to Earth's 23.5 degrees. However, while Earth's obliquity varies by no more than about 2.5 degrees because of the presence of our large Moon, Martian obliquity varies from about 10 degrees to close to 50 degrees over time scales of tens to hundreds of thousands of years. This implies that the planet continues to experience major climate changes — large changes in atmospheric temperature and pressure and the periodic redistribution of Martian water — on a time scale roughly similar to that of Earth's ice age cycles.

Martian atmospheric pressure is nominally about 0.5% to 1% of Earth's 1013 mbars, and, as on Earth, diminishes with increasing altitude. In addition, as mentioned above, atmospheric pressure drops by about 30% during southern winter, and varies daily on the order of 10% due to a thermally driven diurnal atmospheric "tide." The Martian atmosphere is about 96% carbon dioxide, 2% nitrogen, and 2% argon [2]. Geologic evidence indicates that Mars had major oceans 4 billion years ago, and today water makes up most of the polar caps and is also widely distributed across major parts of the planet, presumably as subsurface ice, brines or hydrates. As described above, major redistributions of this water likely occur over timescales of 10,000 to 1 million years. The detection of abundant water has rekindled hopes for the possibility of Martian life present or past, as has the recent discovery of a broad spectrum of extremophile life on Earth.

### **Exploring Mars**

The exploration of Mars by unmanned spacecraft began in the 1960s with the American Mariner flyby missions. It continued through the 1970s with the Viking orbiters and landers. This was followed by various orbiters; the Pathfinder mission with its Sojourner rover in 1997; the Mars Exploration Rovers (MERs) Spirit and Opportunity which landed in January 2004; 2008's high latitude Phoenix lander; and the Mars Science Laboratory (MSL) rover Curiosity which landed in August 2012. Interspersed with the successful missions were many American and Soviet/Russian mission failures, most recently the 2011 Russian Phobos-Grunt effort to return a sample from Phobos. [3]

Perhaps the first serious plan for transporting humans to Mars was outlined by Wernher von Braun in his 1953 book *Das Mars Projekt (The Mars Project)* [4], which proposed an ambitious mission profile involving

giant “three stage ferry vessels” to Low Earth Orbit, “space ships” between LEO and orbit around Mars, and winged “landing boats” to and from the Martian surface. (It was then believed that the Martian atmospheric pressure was about 12% of Earth’s, some 10 to 20 times higher than we now know it to be.)

While von Braun’s *Mars Project* was mere speculation in the early 1950s, the success of the Apollo program in the late 1960s led many people to expect that a human mission to Mars would be undertaken in short order. Instead, the financial pressures of the Vietnam War and the collapse of the Soviet Moon program steered NASA onto the very different path of developing first the space shuttle and then the space station. Hopes for a human Mars program were revived in 1990 when President George H. W. Bush proposed the “Space Exploration Initiative” (SEI) [5], but NASA responded with an unaffordable plan bloated by the inclusion and extension of all of NASA’s existing and proposed research efforts. SEI was dead on arrival in Congress.

In the early 1990s, in response to the demise of SEI, Martin Marietta engineers Bob Zubrin and David Baker developed a mission concept that came to be called “Mars Direct” [6], and several of its key features have since been incorporated into NASA and other “Design Reference Missions” (DRMs) [7]:

- 1) A conjunction mission comprised of a 6+ month transit to Mars, approximately 18 months spent on the surface of Mars, and a 6+ month return;
- 2) Pre-emplacement of unmanned assets, including an Earth Return Vehicle (ERV) or Mars Ascent Vehicle (MAV); and
- 3) In-situ resource utilization (ISRU) to generate fuel (methane) and oxidizer (liquid oxygen) from Martian atmospheric carbon dioxide and hydrogen possibly extracted from Martian water.

While the partitioning of functional elements into specific vehicles differs among the various proposals, this nominally 30+ month conjunction mission profile leveraging pre-emplacement of resources and ISRU now represents a consensus both inside and outside NASA. Unfortunately, while the Mars Direct concept provided at high level a technologically feasible and relatively affordable blueprint for a manned Mars mission, the political will to pursue such a program did not materialize, partly because of the constituency-driven nature of the NASA enterprise. The dream of

human Mars exploration has been kept alive by the Mars Society [8], founded and led by Zubrin, and other efforts of Mars enthusiasts [9].

In 2004, President George W. Bush promulgated a “Vision for Space Exploration” (VSE) [10] with the stated goal of sending humans “to the Moon, Mars, and Beyond.” In fact, however, the Constellation program developed under the leadership of then NASA Administrator Michael Griffin was focused almost completely on getting Americans back into space after retiring the space shuttle fleet in 2010 and then returning to the Moon (nominally by 2020). It paid only the feeblest lip service to the Vision’s stated long term goal of putting humans on Mars.

In 2009, the Obama administration chartered the “Review of U.S. Human Spaceflight Plans Committee” (a.k.a. the “Augustine Committee”) to assess the viability of the Constellation program. The Committee’s report [11] found that NASA’s human spaceflight budgets, as programmed, were totally inadequate. It proposed two alternative long range options, both requiring increased funding:

- 1) Returning humans to the Moon, or
- 2) Following a “Flexible Path,” developing the capability for extended (up to 1 year) human flights beyond Low Earth Orbit, to visit Near Earth Objects (NEOs) and the Earth-Sun Lagrange points.

Getting humans to Mars was explicitly identified as the long-term goal, but characterized as financially out of reach. The Obama administration cancelled Constellation, but elected to continue the development of the Orion Multi-Purpose Crew Vehicle (MPCV) and the heavy-lift Space Launch System (SLS). The Asteroid Retrieval and Recovery Mission (ARRM) was announced in April 2013 — see Appendix B, “Alternatives and Distractions.”

### **Extended Missions, Program, and Base**

As noted in the last section, the consensus profile for bringing humans to Mars is a conjunction mission comprising 6+ month transits to and from Mars, with a surface stay of about 18 months.

#### ***Conjunction Mission Profile***

Using a “Hohmann trajectory” — an elliptical orbit tangent to the orbit of Earth when closest to the Sun, and tangent to the orbit of Mars when farthest — minimizes transit energy requirements, and hence cost. It

is necessary, of course, that when the vehicle arrives at the destination orbit, the destination planet should actually be at that same point in the orbit. This means that Hohmann launch opportunities between Earth and Mars occur every 26 months in each direction, with the return launch window from Mars to Earth occurring about 2 months before the outbound window. A crew can thus return after 18 months on the surface, but also after 44 months, or after 70, 96, and so on.

### ***Program Context Dictates Extended Missions***

Since expected high costs make it unlikely that we will invest in developing a system capable of taking humans to Mars and then use it for just one 18-month surface-stay mission, NASA's Design Reference Architecture (DRA) 5.0 assumes three successive independent missions [12]. We should consider how a sequence of manned Mars flights should be configured to create a rational program — one which maximizes scientific payoff consistent with minimizing costs and risks (maximizing crew safety).

The Apollo program provides a baseline for comparison. A series of 6 independent sorties were made to different locations on the lunar surface in the three and a half years between July 1969 and December 1972, with surface stays ranging from 22 to 75 hours and total mission durations from launch to splashdown of between 8 and 13 days. Launch windows occurred every month when the lighting at the planned landing site was appropriate, so the factor limiting the pace of launches was the assembly and checkout of the required Saturn launch vehicle stages and Apollo command, service, and lunar modules.

This will not be the case with Mars missions. In order to keep the hardware production line and launch and mission control facilities active, we will need to launch during every window — every 26 months. This means that:

- The second mission crew will launch from Earth 2 months after the first has launched on its return from Mars;
- For a period of 4 months, we will have 2 crews in space; and
- The second crew will not arrive on Mars until 8 months after the first crew has left.

Zubrin proposed that the landing points for successive Mars sorties should be chosen no more than about 800 km apart, so that backup resources would always be “just” a long rover ride away. This would be



prudent, of course, but it raises a fairly obvious question: If we want to place a crew at point B on the surface of Mars, and already have a crew at point A about 800 km away from point B, why should we fly the first crew hundreds of millions of km back to Earth, and send a second crew all the way from Earth? Why not send a good ground transport vehicle and plan to have the first crew drive it from point A to the prepared site at point B? The risks of spaceflight are associated first with launch (shuttle Challenger), then with landing (shuttle Columbia, Soyuz 1 and Soyuz 11), and thirdly with cruise (Apollo 13). Being on the ground, on Mars as well as on Earth, is intrinsically much safer than being in space, and it is relatively easy to make it safer still. Since the basic conjunction mission calls for more time on the surface of Mars (18 months) than in transit (12-14 months), it pays to invest in making the surface stay as safe as possible. In fact, we have a “virtuous cycle”:

- 1) The longer we are planning to stay on the surface of Mars, the safer we can and should make it; and
- 2) The safer it is on the surface of Mars, the longer we should plan to stay!

Consider the following program plan: An initial crew (of 4 to 6 people) is launched to a carefully prepared site, and remains on the surface of Mars for a full 96 months, returning on the fourth minimum-energy Hohmann opportunity. A second crew follows to the same site 26 months later, and also stays for 96 months. Thus, we have 8-12 people at the base for a period of 70 months, we have no gaps in crew presence on Mars, and the mission operations team never has to deal with two crews in transit at the same time. We continue to build assets at the initial landing site, expanding to a second site only when the first base has achieved true critical mass. Instead of launching an Earth Return Vehicle to Mars 26 months *before* the *first* crew, we send it 26 months *after* the *second* crew. Moreover, the first return launch of the ERV can be an unmanned test flight carrying Mars samples back to Earth, and we will have the advantage of having “ground crew” to service its launch. Finally, because we are delaying the launch of the first ERV, we can also defer its development, thus employing a smaller team of rocket developers for a longer period of time [13].

Table 1 below presents a comparison of a Base First program with a program comprised of 5 independent 18-month conjunction missions.

**Table 1.** Comparison of the “Base First” plan with a program comprised of a sequence of five independent conjunction missions

|  | <b>Mars Base First Program<br/>(2-96 month surface stays)</b> | <b>5 Conjunction missions<br/>(18 month surface stays)</b> |
|--|---|--|
| Time from first crew arrival to last departure | 122 months  | 122 months   |
| Time 2 crews on Mars                           | 70 months (1@70 mo)   | --   |
| Time 1 crew on Mars                            | 52 months (2@26 mo)   | 90 months (5@18 mo)  |
| Gap: 0 crews on Mars                           | --  | 32 months (4@8 mo)   |
| # crews launched                               | 2   | 5  |
| EDL mass requirement                           | 6-10 tonnes   | 40 tonnes  |
| First ERV/MAV launch                           | 52 months <i>after</i> first crew launch                      | 26 months <i>before</i> first crew launch                  |

*Extended Missions Dictate Early Base Establishment*

It is clear that supporting a crew of 8-12 people on the surface of Mars for 10 full years is a very different proposition from supporting 4-6 people for 18 months. NASA’s DRA 5.0 and other Design Reference Missions all the way back to the Mars Direct plan envision the crew living inside a habitat sitting on the surface. EDL (NASA-speak for Entry, Descent and Landing) to get this nominally 10-meter diameter 40-tonne “tuna can” unit to the surface of Mars in one piece represents a major technological challenge.

The alternative approach proposed here for the “Base First” plan would have the crew live and work in underground tunnels constructed by robots before the crew arrives, creating a true Mars Base. Living underground would provide much better protection than a surface habitat against radiation, which — while much less intense on the Martian surface than in interplanetary space — is much more intense than on Earth or in Low Earth Orbit [14]. This approach also carries the additional advantage that a crew-landing vehicle could be much smaller than the 40 tonne tuna can habitat, greatly reducing the structural mass that would have to be brought from Earth, and radically simplifying the Entry/Descent/Landing problem [13]. For comparison, the Apollo Command Module (CM) weighed 6 tonnes, while the Apollo Lunar Module (LM), including both descent and ascent stages, was 15 tonnes.

---

The underground space would be quickly and continually expanded to eventually include:

- living, sleeping, and dining areas, galley, pantry, and garden;
- medical/dental clinic with mini-intensive care unit, exercise facilities (gym and track), spa, and swimming pool;
- medical, biological, chemical, and geological laboratories;
- manufacturing and repair shops; and
- storage for food, other supplies, spare parts, and collections of samples.

Many critical systems will be required to support human life and mission operations — including thermal control, air, water, waste, computing, and communications — but these various subsystems can be installed in the constructed underground base in a much more loosely coupled manner than would be possible in a tightly integrated habitat transported from Earth, thus simplifying component repair and replacement.

### **The Challenges of the Base First Program**

The concept of a base on Mars is obviously not a new one; however, a common thread among mainstream (i.e., space agencies and contractors) thinking is the implicit assumption that the establishment of a base should occur only after a sequence of human sorties to identify the best location. The key arguments in this paper are that we should:

- 1) Plan for a Mars base beginning with the first humans we send to Mars;
- 2) Plan to send fewer people to Mars, but have each of them stay much longer; and
- 3) Invest heavily up-front in developing and refining the surface segment of the human Mars mission because travelers to Mars will spend (much) more time on the surface of Mars than in space, and this is where the critical challenges and payoffs lie.

This will require either that NASA move well beyond its traditional focus on space transportation systems, or that one or more other entities assume a leadership role in the Mars exploration enterprise.

One very recently initiated effort that is decidedly *not* mainstream is MarsOne [15], a Dutch-based organization working to establish a permanent Martian colony by sending 4-person crews to Mars starting in

2023. Something like 100,000 people have already applied online to make this 1-way trip to Mars. Successfully executing the MarsOne project will require overcoming serious challenges in raising the required funding and in actually developing the required systems in time to meet the proposed schedule. It is not unlikely that MarsOne (like NASA) will focus very heavily on the highly visible transportation components, at the expense of the ground-based “system of systems” necessary to support a viable Mars colony. The Base First strategy proposed in this paper explicitly addresses this requirement, and — because everyone returns to Earth — it avoids a commitment for the indefinite support of a Martian colony. On the other hand, it is clear that Base First deliberately cultivates the option for an *informed* future decision to establish a permanent base or colony.

### ***Can Humans Survive and Succeed on a 10-year Mission?***

Some may object that a mission profile calling for an 8-year stay on the surface of Mars (and 10 years away from Earth) is unreasonable — that the psychological stresses of living in such a small isolated group for so long would put the success of the mission, if not the crew’s survival, at unacceptable risk. However, the history (and especially the prehistory) of humanity is one of many small groups of people migrating into the unknown with no intention of returning, and we find many examples of small groups that have successfully lived in nearly constant isolation, including bands of hunter-gatherers, Inuit family groups, pre-20th century ship crews, castaways, and some soldiers and prisoners.

However, while humans on Mars will be physically isolated from Earth, they will have high bandwidth connectivity to the rest of the humanity (albeit with a 6-44 minute round trip latency). They need not be lonely; the World Wide Web will expand into the Solar System Wide Web. But we must thoroughly explore the full range of issues associated with long-term connected-but-physically-isolated living, including understanding how and how well high-bandwidth long-latency network communications can compensate for the lack of physical contact. And we must develop an experience base on Earth before we dare send people on such a mission. Since it is likely that the success of the mission may depend on the “chemistry” of the specific personalities involved, it may be that a crew should begin living together as a coherent group (if not in full isolation) well before their launch. The psychological and psychiatric issues associated with spaceflight have been studied since the beginning of the space age; see, for example, [16], [17], [18].

Since living beneath 5 meters of regolith will mitigate the radiation hazard on the surface, the principal physiological challenge posed by the Base First mission (beyond those posed by a 30-month conjunction mission) is the loss of bone density and strength associated with the outward and return 6+ month zero gravity transits and eight years of 0.38 g Mars gravity. A focused exercise regimen, possibly combined with dietary modification, should at least partially mitigate these effects [19], and at some point it might be possible to install a one-g centrifuge in the base. Long-term exposure to a low-pressure high-oxygen atmosphere in the base habitat — which could be adopted in order to reduce Extravehicular Activity (EVA) pre-breathe time [20] [21, p. 20] — would constitute a second physiological risk factor. However, this is a risk that can be evaluated by experimentation on Earth (see Appendix A).

An advantage of the base-first exploration strategy is that it will allow people to extend their stay on Mars, which would be absolutely necessary if the Earth Return Vehicle or Mars Ascent Vehicle could not be made ready during the return launch window, and might be desirable in other cases. Imagine, for example, that the crew exobiologist on the first conjunction mission were to discover living Martian life just a few weeks before she is scheduled to return to Earth. And, of course, one of the classic planetary exploration science fiction tropes (e.g., [22], [23], [24]) is that, when it is time to return to Earth, one or two characters (usually a couple) simply announce “we’re going to stay.”

### ***Required Technologies and Tools***

Viewed from an engineering perspective, it is clear that a Mars base will constitute a complex “system of systems,” one whose development will involve a large number of technical disciplines, and this fact must be explicitly acknowledged if we are to succeed. Here is a listing of some of the technologies and tools we will need to develop in order to create a human base on Mars:

- surface nuclear power plant (nominally 150 kW electrical, plus thermal energy)
- cryogenic storage and handling tools/systems
- thermal control systems (including insulation) — different on Mars than in space
- methane (and/or propane?)-oxygen power sources (electrical, thermal, motive; very small to very large)

- maximally-autonomous robotic systems
- vehicles (manned and unmanned/robotic, ground and air, pressurized and unpressurized, all sizes)
- construction technologies and equipment (including robots, autonomous or supervised)
- communications and navigation systems (intra-base, off-base, and off-planet; supporting systems, vehicles, and people)
- small-scale (“personal”) manufacturing technologies, paired with extraction/ development of appropriate material feedstocks
- medical strategies/tools: auto-medicine (taking care of yourself), para-medicine (taking care of each other), and tele-medicine (accessing medical resources back on Earth)
- ultra-reliable computing and other IT support (redundant, radiation-hard; wearable systems, etc.)

Not only is this not “rocket science,” it’s not even just technology. We need to think about the following:

- construction, physiology, and robotics;
- psychology and sociology;
- nutrition, gardening, and medicine;
- architecture, history, insulation, and HVAC;
- power distribution, IT, sensors, and artificial intelligence (AI);
- biology, chemistry, geology, and seismology;
- and ...

In fact, the successful development of an effective base on Mars will require more than a solid systems-centric engineering perspective. It will also require a human-centric perspective, involving numerous social as well as technical disciplines. In essence, we are attempting to design the smallest-scale possible viable human economy and supporting ecology, and we don’t know in advance what this “nano-society” should (or even could) look like.

However, NASA as an organization is focused on the “rocket science.” To understate the case considerably, “studies of surface activities and related systems have not always been carried out to the same breadth or depth as those focused on the space transportation and entry or ascent systems needed for a Mars mission” [21]. Perhaps the National Science

Foundation (NSF), with its broad scientific purview and experience managing U.S. Antarctic bases, might effectively participate in the development of the Mars base.

### *Base Development Process and Technology Context*

Developing all the pieces for an effective base on Mars will be a complex undertaking, one quite distinct from the development of the system that will be required to transport humans to and from Mars. What is required is the development of an overall plan, starting from the physiological and psychological needs of a human crew, defining their task-oriented and other activities, leading to system and subsystem models, assessing and adopting/adapting technologies to implement them, and eventually validating the various subsystems through extensive testing and simulations here on Earth [20][25]. This should be a “spiral” process that will be iterated until it is time to go, with multiple agencies/entities involved (e.g., development of a surface-sited nuclear power plant by the Department of Energy). The initiation of this activity need not and should not wait for a specific commitment to build the Mars transportation system. Perhaps the most difficult challenge will be to manage a complicated program with a relatively small budget (as compared to rocket development), across multiple agencies, over a period of many years.

Many technologies and systems developed for Earth will be carried unchanged to Mars. Others will have to be adapted to the particular situation of our Mars base. Rapidly changing technology complicates the development process. For example, at what point do we decide to adopt or adapt a given product or system for inclusion in our long-term Earth-based Mars base prototyping/ simulation enterprise? We can freely experiment with commercial-off-the-shelf (COTS) elements, but the decision to embark on a costly program to modify existing products for use on Mars must not be taken too early, or we will — like the U.S. military with its communications systems — be trapped in an expensive web of obsolete proprietary systems even as the rest of the world adopts technologies with much higher performance and much lower cost.

The rapid evolution of technology also carries short-term challenges with respect to what we actually send to Mars. Given the 26-month synodic period between launch windows, an assembly-test-launch (ATL) time that is not much shorter, and the 12-18 month COTS electronics product innovation cycle, we will have to decide whether to introduce a new generation of IT for each successive mission. It will

clearly be impossible to perform a full-mission duration test of new subsystems as they are deployed. Fortunately, the loose coupling of subsystems in the Mars base environment will allow easy module upgrades and the use of redundant units to ensure system-level reliability.

### **Conclusion**

Because of the limitations placed by orbital mechanics on energy-affordable transits between Earth and Mars (transits that last 6+ months, and are possible only every 26 months), it would be suboptimal to execute the initial human exploration of Mars as a sequence of independent sorties analogous to the Apollo program. Costs and risks can be significantly reduced by pursuing a program in which the first humans we send to Mars remain there for many (nominally 8) years [13][26], living and working in a safe and productive underground base constructed in advance of their arrival by robots [27][28]. Twenty-six months after the first crew's arrival, a second crew will land at the same base, and other sites of interest can be visited using ground vehicles. Such a program-level architecture:

- affords a continuous human presence on Mars,
- provides better shielding from radiation,
- reduces the number of crew transits from and to Earth,
- greatly reduces the maximum mass requirement for Entry/Descent/Landing,
- permits deferred development of the return vehicle (which could otherwise be a schedule-limiting element), and
- allows an initial unmanned return vehicle test supported by “ground crew” to return samples to Earth.

Adoption of a “Base First” exploration program will require us to acknowledge and engage the real challenges to the human exploration and colonization of Mars — maintaining the safety, health, productivity, and happiness of a very small population of humans on the surface of Mars for an extended period of time. Apollo/Saturn proved that powerful rocket systems can be developed in less than a decade, but the Mars surface stay presents many specific technical and non-technical challenges that have nothing to do with “rocket science.” Now is the time to start thinking seriously about these issues.



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## Appendix A: Short-Term Agenda for NASA

While this paper has argued strongly that preparation for a human stay on Mars requires much more than NASA, there are several issue areas that do require NASA's unique expertise, and these should be addressed as soon as possible.

### *Physiological Effects of Martian Gravity*

Over the past several decades, many astronauts and cosmonauts on Skylab, Mir, and the International Space Station (ISS) have experienced periods of zero-g (microgravity) longer than the planned 6-7 month transit to Mars. A number of serious physiological effects have been studied, and some strategies have been developed for mitigating them, as well as for dealing with the other challenges of zero-g — eating, showering, pooping, etc. [29]. But we have no experience base whatsoever with Mars's 38% gravity. It is clear that many of the minor inconveniences of zero-g will not apply on Mars, but we do not know to what degree (if at all) the stay on the Martian surface will support recovery from the physiological effects of zero-g. The longer we are planning to stay on the Martian surface, the more critical it is to understand the long term effects of 38% gravity, and this can only be done in space. Experiments with mice in a centrifuge installed on the ISS would provide an important first step. Exploring partial gravity on the ISS has been proposed multiple times, but never funded.

### *Habitat Atmosphere: Pressure and Composition*

Beyond the baseline requirements of providing enough oxygen, eliminating carbon dioxide, and managing humidity, some key factors for selecting the atmosphere for manned spacecraft, specifically for the Mars base habitat, are these:

- Reducing habitat pressure reduces required habitat pressure strength and atmospheric leakage to space.
- Reducing spacesuit pressure decreases suit weight, complexity, and cost, and increases flexibility and comfort by reducing the work required for astronaut movement.
- The risk of decompression sickness (DCS) or “the bends” at the start of an Extravehicular Activity (EVA) increases with increasing ratio of nitrogen partial pressure in the habitat to the total spacesuit pressure.

- Increasing oxygen percentage increases flammability, complicating both prevention and suppression of fire.

The ISS, like the space shuttle before it, provides a standard Earth sea level atmosphere — 14.7 pounds per square inch (psi) and 21% oxygen. As a result, preparation for an ISS EVA requires 4 hours of breathing pure oxygen, followed by 17 hours of 30% oxygen at 10.2 psi, followed by another hour of pure oxygen, before donning the EMU (“Extravehicular Maneuvering Unit” spacesuit) with 100% oxygen at 4.3 psi.

However, this long delay will not be acceptable at a base on Mars. When something “outside” in the extended base complex goes “thump” in the night, astronauts’ lives may well depend on them being able to go out to check on it immediately. A habitat atmosphere of 40% oxygen at 6.0 psi, together with a suit atmosphere of pure oxygen at 3.0 psi would reduce the risk of decompression sickness to an acceptable level [20].

The mainstream of NASA’s thinking, however, seems to run along very different lines. Apart from Skylab in the 1970s, NASA has used 30% as the acceptable upper limit for oxygen, except in suits and pre-breathing. It is not clear, however, that 30% has been adopted as a formal limit. Nor is the documentation for NASA’s decision-making compelling or complete. It appears that NASA decision-makers have *assumed* away the low-pressure approach. In some cases, charts have been truncated so that neither a 3.0 psi suit nor a 6.0 psi habitat even appear [30].

Moreover, the NASA approach to dealing with DCS has been to work to develop higher pressure suits, and this is what NASA means when the phrase “advanced suit” is used. Meanwhile, work on a radically different alternative approach — a low-pressure mechanical counter-pressure (MCP) suit — has been pursued at a low level for decades [31][32]. (Think “wetsuit and scuba” as opposed to “hardhat diver.”)

The bottom line is the following: Since an emergency on Mars may require an immediate EVA, the Mars habitat’s atmosphere and, by extension, the atmosphere in the transit “deep space” habitat should be low pressure and oxygen-rich. NASA should: (1) explore the full range of options and (2) develop an extensive experience base for the adopted atmospheric parameters, both on Earth and in near-Earth space. This should be done as soon as possible since many design decisions depend on it. Unfortunately, the default for the Orion Multi-purpose Crew Vehicle is a standard sea level Earth atmosphere.

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## ***Martian Entry, Descent, and Landing for High Mass Payloads***

The “skycrane” that successfully brought the 1 tonne MSL Curiosity to the Martian surface in Gale Crater in August 2012 represented a major advance over the airbags used by Mars Exploration Rovers Spirit and Opportunity. NASA is planning to use the skycrane again for another rover in 2020. However this approach cannot handle Entry/Descent/Landing for a manned mission that will almost certainly exceed 10 tonnes. NASA should also immediately start the development of one or more new Mars EDL schemes to handle payloads in the range of 10 to 40 tonnes. Understanding whether it is most cost effective to land 40 tonnes in one piece, in two 20-tonne pieces, or in four 10-tonne pieces, is necessary to inform the design of the entire Mars mission system, from launch vehicles to human landers to surface habitats.

## **Appendix B: Alternatives and Distractions**

The introduction to this paper posited that “the planet Mars is far and away the single best choice for an initial extended human presence beyond low Earth orbit.” If we accept that, and if humans are *ever* going to travel *anywhere* in space, then they are going to go to Mars. So the actual question is not *if*, but *when* we will send humans to Mars.

### ***Why Not Just Continue To Use Robots Instead of Humans?***

Thinking in the short term, however, human and robotic exploration of space are often framed as mutually exclusive alternatives. Why should we spend a lot of money to send humans to Mars when robotic missions from the Viking landers of the 1970s to the Opportunity and Curiosity rovers active in 2013 have made so many important discoveries at a tiny fraction of the cost?

The principal reason is simple physics. The 6-44 minute round trip light-speed latency of communications between Earth and Mars precludes robotic teleoperation. Consequently, today we operate our Mars rovers with a single command cycle per sol: We send a command sequence to the rover and wait until the next sol to receive the results of the command execution, then repeat the process. While the software evolves over time so that we incrementally increase the payoff from each sol’s work, it is still painfully slow, as is clear to anyone following the daily adventures of Curiosity.

So the conclusion is this: The robots we have deployed, and the robots we are going to be able to deploy in the next few decades, are

simply not able to do what humans can do, and it takes so long for them to do what they can do, that sending humans to Mars *will* become competitive if we believe that Mars is indeed worthy of serious exploration.

In fact, the time when we finally send humans to Mars, presumably a few decades from now, will not mark the end of the involvement of unmanned systems in the exploration of Mars. Instead, robots and other unmanned systems will continue to play many critical roles on Mars, and the presence of humans will strongly affect the characteristics of the robotic systems we build. In advance of the first human landings, the descendants of today's rovers will: survey candidate landing sites; identify and locate ice and mineral resources; establish power, communications, and navigation infrastructure; and construct underground habitats. Many of these systems will require much more strength and power than exploration rovers.

Once humans have landed, mobile robots will continue to explore and preview sites for human exploration, identifying targets of interest and possible hazards. They will also perform ongoing construction tasks and transport equipment, supplies, and people. The arrival of humans on Mars will permit proactive maintenance and repair, and allow teleoperation and operator intervention, supporting multiple dynamic levels of autonomy. Therefore, the critical challenges to the use of unmanned systems will occur before humans arrive on Mars. Nevertheless, installed communications and navigation infrastructure should be able to support structured and/or repetitive operations (such as excavation, drilling, or construction) within a "familiar" operating area with an acceptable level of remote operator intervention [27][28].

The single most limited resource on Mars will be human attention. Each person we send to Mars will require a huge investment in mass to be transported, and therefore in cost. It will be highly cost effective to create systems and procedures to leverage the attentional energy of each human on Mars — to do the most with the fewest people — and this can only be done by using "smart systems," including robots. The question is not "robots *instead of* humans on Mars"; instead, the answer is "robots *before* humans and robots *with* humans on Mars."

### ***Why Not Go Back to the Moon?***

Some have suggested that a return to the Moon is a logical step on the path of sending humans to Mars. Let's examine and dismiss some of

the arguments in turn:

**Use the Moon as a refueling stop?** The lunar gravity well is deep enough that retrieving fuel from a depot on the surface of the Moon is energetically more expensive than bringing fuel from Earth, even if it were free.

**Use lunar in-situ resource utilization to prepare for Martian ISRU?** The resources available on the surface of the Moon are totally different from those we plan to exploit on Mars, especially carbon dioxide extracted from the atmosphere and water from subsurface ice, brines, or hydrates.

**Use a long-term outpost on the Moon to prepare for Mars?** Lunar gravity is a greater challenge than Mars gravity. Lunar day (an Earth month) is a greater challenge than Mars day, which is nearly the same as Earth's. Lunar dust is "sharp," and offers a greater challenge than Mars dust, which has been rounded off by wind action. Heck, Mars is a great place to prepare for putting an outpost on the Moon!

**Use Lunar Entry/Descent/Landing to prepare for Mars EDL?** Parachutes work on Earth, while a retrorocket scheme is both necessary and sufficient on the Moon. The Mars atmosphere is thin enough that delivering large (say, 10+ tonne) payloads to the surface requires more than parachutes, but at the same time it is thick enough to interact with retrorocket exhaust at high velocities. The Moon can't teach us anything here.

The bottom line on this issue is that a decision to send humans back to the Moon would — by diverting financial, personnel, and attentional resources — effectively delay the human exploration of Mars by years, if not decades. Louis Friedmann, former Executive Director of the Planetary Society, put it well: "We should go to the Moon, and we did!"

### ***Why Not Go to a Near Earth Object?***

Sending humans to an appropriate Near Earth Object as part of the "Flexible Path" strategy would provide a good demonstration/rehearsal for the transit stage "deep space habitat" (DSH) that will carry humans to Mars. The criteria for selecting a target NEO include:

- 1) The energy ("delta-v") required to send people to the NEO and back must actually be affordable;

- 2) The total time required for the transit to and from the NEO should be comparable to a transit to or from Mars (6-12 months); and
- 3) The NEO must be large enough so that we can rendezvous and land on it (many NEOs with a diameter less than about 50-70 meters are rotating too fast to actually rendezvous with and “land on.”)

It turns out that the number of actual NEOs that satisfy all these criteria is very small.

But this point is now moot, since NASA has recently adopted an alternate strategy, the Asteroid Retrieval and Recovery Mission (ARRM). Since the deep space habitat will not be ready by the early 2020s, instead of sending astronauts to an asteroid, NASA proposes to use an unmanned spacecraft to capture a small (roughly 8-meter diameter) asteroid intact and bring it back to a stable distant retrograde orbit in the Earth-Moon system. This is close enough so that astronauts can visit and sample it using the Orion MPCV. While the retrieval mission would test out advanced solar electric propulsion, this expensive pair of missions will, of course, divert resources from preparing for an actual human mission to Mars. The retrieval component of ARRM should be canceled and the recovery effort redirected toward the tiny “mini-moons” (softball to dishwasher sized) that frequently enter the Earth-Moon system and remain for periods of up to a few years [33].

The fact that two private companies have recently been founded with the goal of actually mining asteroids — Planetary Resources Corporation (PRC) and Deep Space Industries (DSI) — makes the expenditure of scarce public funds for the NASA ARRM effort even less sensible.

### ***Don't We Need (fill in the blank) Before We Can Send Humans to Mars?***

A number of “exotic” propulsion schemes — alternatives to chemical rockets — have been or are being developed, and these are sometimes held out as being necessary before we can send humans to Mars [34]. For example:

- A Nuclear Thermal Rocket (NTR) propulsion system could support a faster human transit to Mars and reduce the cost of cargo transfer. An NTR system was fully developed in the 1960s, but the politics involved in using a nuclear approach would be fierce.

- Ion propulsion is capable of providing continuous (but very low) thrust at very high specific impulse (a measure of “bounce to the ounce”). Such a low thrust modality might well provide a very cost effective transportation scheme to bring cargo to Mars with 20-30 months transit time, since much less fuel mass would have to be launched to Low Earth Orbit in order to deliver a given payload mass to the surface of Mars, as compared to chemical rockets.

But we don't *need* either of these schemes (or more futuristic schemes such as fusion rocket propulsion or a “space elevator”) to send the first humans to Mars. Chemical rockets, on a scale not much greater than Saturn/Apollo, will do the job.

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## Bio

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# **A Brief History of Government Policies to Promote Commercial Space<sup>1</sup>**

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## **Abstract**

This paper discusses the history of private and government support of private sector activities in the United States. Through a review of government legislations over the last many decades, it demonstrates that, despite perceptions, space activities for commercial purposes are not new, and private sector firms engaged in commercial activity have had public, private and government support for decades. A review of the history goes beyond a simple itemization of government activity. As several U.S. government agencies gear up to support increasing numbers of private firms in the space sector, there are many lessons that can be drawn from prior attempts. The lessons from these activities should be incorporated in future policy design and planning.

## **Introduction**

**THERE HAS BEEN A MAJOR EFFORT** in the United States to bring the private sector into the primarily government-controlled space sector, and, in recent years, there have been many high-profile non-governmental developments in space. In 2012, Space Exploration Technologies (SpaceX) — delivered cargo to the International Space Station (ISS) under a fixed-price contract with the National Aeronautics and Space Administration (NASA). It is expected that SpaceX and other firms will take crew to the ISS by 2015. Other private and publicly held firms have similarly ambitious plans; though not all might be realistic or feasible. Recently formed firms Planetary Resources and Deep Space Industries intend to survey and mine asteroids. California-based firm Moon Express, among other firms, has announced its intention to win the Google X Prize (a \$30-million prize to the first privately funded teams to land a robot on the surface of the Moon safely) and to use robots to start mining the Moon. Texas-based Shackleton Energy Company plans to mine ice in the Shackleton Crater at the lunar South Pole to provide propellant for planetary missions. Other companies have made forays into earth observation and remote sense. The start-up firm Planet Labs is expected to revolutionize Earth observation by providing low-cost high-resolution imagery quickly and inexpensively. Similar to Planet Labs, Skybox

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focuses on imaging, and is combining web technology with a constellation of microsatellites to deliver insight into daily global activity.

Despite perceptions that commercial space has recently arisen, it has been long in the making. Commercialization of space was anticipated by space enthusiasts long before government arrived, and its seeming recent emergence may well be a “re-emergence.” This paper discusses the history of commercial space activities in the United States, with the argument that there may be many lessons, especially related to government policy, from past successes and failures, that are worth incorporating as government agencies such as NASA, the Federal Aviation Administration (FAA), Defense Advanced Research Projects Agency (DARPA) and others ponder ways to support the “nascent” private space sector.

As the sections below show, the history of commercial space can be segmented into three major eras — early beginnings, referring to activities well before the start of the modern space age; fast forwarding to the 1980s which saw the first government effort to bring private sector into the largely government-run space enterprise of the Apollo era; and activities in the 2000s and beyond.

### **Early Beginnings**

Private funders played a dominant role in funding early American “space-oriented” projects. These individuals had largely scientific aspirations and not commercial ones in mind, and their efforts were primarily concentrated in ground-based astronomical observatories. As Table 1 shows, most early large observatories in the United States were privately funded. The primary source of funds was wealthy individuals who were either indulging a personal interest in astronomy or who were interested in leaving to the world a personal legacy and monument. Examples of this type of patronage are the observatories built by Andrew Carnegie, James Lick, Leander McCormick, Charles Yerkes, and John Rockefeller’s General Education Board.

The funding was also economically significant. Table 1 provides the 2008 gross domestic product (GDP) ratio equivalent values for a number of American observatories and space exploration projects in the nineteenth and early twentieth centuries. As the table illustrates, projects ranged in cost from around \$50 million to upwards of \$1 billion. Indeed, according to some experts, the recent emergence of commercial space activities is, in fact, a re-emergence:

For the majority of its history, space exploration in America has been funded privately. The trend of wealthy individuals ... devoting some of their resources to the exploration of space is not an emerging one, it is the long-run, dominant trend which is now reemerging (MacDonald, 2010).

Table 1. Early Astronomy Projects

| Project                                  | Year | Cost        | 2008 GDP Ratio Equivalent Value |
|--|------|-------------|---------------------------------|
| University of North Carolina Observatory | 1831 | \$6,430     | \$89,000,000                    |
| Williams College Observatory             | 1836 | \$6,100     | \$60,000,000                    |
| West Point Academy Observatory           | 1842 | \$5,000     | \$45,000,000                    |
| U.S. Naval Observatory                   | 1842 | \$25,000    | \$225,000,000                   |
| Cincinnati Observatory                   | 1843 | \$16,000    | \$149,000,000                   |
| Harvard College Observatory              | 1843 | \$25,000    | \$233,000,000                   |
| -Edward Phillips Endowment               | 1848 | \$100,000   | \$601,000,000                   |
| Georgetown Observatory                   | 1844 | \$18,000    | \$154,000,000                   |
| Detroit Observatory                      | 1852 | \$17,000    | \$81,000,000                    |
| Shattuck Observatory                     | 1852 | \$11,000    | \$52,000,000                    |
| Hamilton College Observatory             | 1852 | \$15,000    | \$71,000,000                    |
| Dudley Observatory                       | 1852 | \$119,000   | \$566,000,000                   |
| Dearborn Observatory                     | 1865 | \$25,000    | \$37,000,000                    |
| Transit of Venus Expedition              | 1872 | \$177,000   | \$310,000,000                   |
| Lick Observatory                         | 1876 | \$700,000   | \$1,220,000,000                 |
| Warner Observatory                       | 1880 | \$100,000   | \$139,000,000                   |
| Transit of Venus Expedition              | 1882 | \$85,000    | \$101,000,000                   |
| McCormick Observatory                    | 1881 | \$135,000   | \$168,000,000                   |
| Yerkes Observatory                       | 1892 | \$500,000   | \$441,000,000                   |
| Mt. Wilson Observatory                   | 1910 | \$945,000   | \$408,000,000                   |
| Mt. Palomar Observatory                  | 1928 | \$6,550,000 | \$972,000,000                   |
| McDonald Observatory                     | 1939 | \$840,000   | \$132,000,000                   |

Source: MacDonald 2008

Arguably, these science-oriented efforts and the inaccessibility of space encouraged a communal belief that space was the province of science.<sup>2</sup> In the early development of American liquid-fuel rocketry, pioneers such as Robert Goddard undertook their research and development (R&D) largely using private funds and, in some cases (as with Goddard), private philanthropy (Pendray, 1964). Goddard was also funded by the Smithsonian Institution.<sup>3</sup> Although the U.S. Government funded some battlefield rocket research during World War I, during the interwar years, only Germany and the Soviet Union aggressively supported rocket research with government money (Raushenbakh and Biryukov, 1968; Neufeld, 1996).

While rocketry programs were beginning to attract military funding during the World War II (with the U.S. Government making a massive effort to acquire the German rocket scientists after the fall of Germany), the growth of public sector support for rocketry and spaceflight began to outweigh that of private companies and individuals with the beginning of the Cold War and later the launch of Sputnik.

Even as the U.S. government centralized leadership in space-related research, development, test, evaluation, and exploration during the U.S.-USSR Space Race, private companies were extensively involved and increasingly interested in the evolutionary development of space technology and space capabilities. Some private companies were even interested in their own space ventures, particularly in the realm of commercial satellites. AT&T Bell served as a pioneer in this field. Not only did it co-sponsor the NASA Echo project, but it also invested \$170 million of its money into its own successful satellite program,<sup>4</sup> Telstar, the cost of which included paying for launch services from NASA (Chaddha, 2009). Hughes Space and Telecommunications, whose Syncom satellite of 1963 pioneered geosynchronous communication satellite design, effectively “forced” itself upon NASA to secure a sole-source contract for the then-controversial GEO satellite. Despite AT&T and RCA’s background and early success, the Hughes GEO design went on to dominate the communications satellite field.

A growing concern over a potential telecommunications monopoly from space led to the 1962 Communications Satellite Act. The act provided for the formation of Communications Satellite Corporation (COMSAT), a public-private entity that was given a monopoly over satellite communications subject to federal oversight and regulation. Likewise, growing international demand for satellite telecommunications

## **Legal and Policy Guidance on Commercial Space: 1980s-1990s**

**The Commercial Space Launch Act of 1984** states the need “... to promote economic growth and entrepreneurial activity through the use of the space environment for peaceful purposes.”

### **1984 Land Remote Sensing Commercialization Act**

**The 1985 Amendments to the National Aeronautics and Space Act (P.L. 85568)** directs that NASA “shall ... seek and encourage, to the maximum extent possible, the fullest commercial use of space.”

### **1988 Land Remote Sensing Commercialization Act**

**Launch Services Purchase Act of 1990** required NASA “to purchase launch services for its primary payloads from commercial provider whenever such services are required in the course of its activities.”

**U.S. Commercial Space Guidelines 1991 (NSPD-3)** provided guidelines to “promote the policy of driving down market costs for private space through government investment.”

### **1992 Land Remote Sensing Commercialization Act**

**The Commercial Space Act of 1998 (P.L. 105303)** states that “to the maximum extent practicable, the federal government shall plan missions to accommodate the space transportation services capabilities of United States commercial providers; a priority goal of constructing the International Space Station is the economic development of Earth orbital space; and competitive markets ... should therefore govern the economic development of Earth orbital space.”

led to the creation of the International Telecommunications Satellite Organization — better known as Intelsat — in 1964, an organization that effectively allowed each country to monopolize control of their international satellite communications. Satellite communications control would only be fully returned to the private sector from these monopolies by the turn of the century.<sup>5</sup>

## **The 1980s and 1990s**

The 1980s saw a convergence of factors that encouraged the rebirth of private sector involvement in space. First, a wave of private sector companies began to challenge the government’s hold on space technologies. In 1984, PanAmSat was organized and became the first private satellite company to challenge the intergovernmental satellite monopoly Intelsat. Even more significantly, the French public launch service company Arianespace SA, founded in 1980, began to provide a new challenge to NASA’s launches and to American preeminence in the exploitation of space technology itself (Fuller, *et al.* 2011).

The rise of a new commercially oriented (albeit state-owned) launch company in Europe would soon prove a stronger competitor to the American aerospace industry. Arianespace quickly became the global leader in commercial launch, surpassing the United States in 1986, and never looking back with the exception of 2004. Ironically, it was the U.S. government that helped to create Arianespace, in part, when NASA refused to launch a French-German commercial

satellite called *Symphonie*. This competition, however, complemented the Reagan administration's goals of deregulation and commercialization, and, in 1984, Congress passed the Commercial Space Launch Act. The goal of the act was "to promote economic growth and entrepreneurial activity through use of the space environment ... [and] to encourage the United States private sector provide launch vehicles, reentry vehicles, and associated services" (Stone, 2012).

As part of the Administration space policy, this act was viewed as a key step toward their goals of the eventual commercialization of space. As President Reagan stated during the signing ceremony:

One of the important objectives of my administration has been, and will continue to be, the encouragement of the private sector in commercial space endeavors. Fragmentation and shared authority had unnecessarily complicated the process of approving activities in space. Enactment of this legislation is a milestone in our efforts to address the need of private companies interested in launching payloads to have ready access to space.<sup>6</sup>

The act allowed private companies to launch their own vehicles provided that they obtain a license from the U.S. Department of Transportation (DOT), which set up the AST (or Office of Commercial Space Transportation) with the responsibility to regulate the U.S. commercial space launch, encourage and promote commercial space launches, recommend policy changes, and facilitate the expansion of space transport infrastructure. The U.S. Department of Commerce (DOC) also set up an additional office, the Office of Space Commercialization (OSC), for the support of commercial space companies.

It was during this time that NASA changed its approach to private space. Before the Shuttle first flew, NASA had initiated a so-called "Getaway Special" program that encouraged researchers in the science and technology community to develop small payloads and experiments that could be carried into orbit on a non-interference basis with the larger and more sophisticated payloads anticipated for Shuttle launch. While this program did not dramatically transform private space, it nevertheless spoke to the agency's growing recognition that the nature of space operations was rapidly changing away from an exclusively government-supported model.



In 1985, Congress amended the original NASA Act during its reauthorization, adding subsection (c) that required the agency to “seek and encourage, to the maximum extent possible, the fullest commercial use of space” (NASA, 2008). NASA support of the commercial use of space was strengthened by the addition of requirements that NASA “encourage and provide for federal government use of commercially provided space services and hardware, consistent with the requirements of the federal government.”<sup>7</sup>

The full effect of this mission change would not be known, however, since it was followed closely by the 1986 *Challenger* disaster. The disaster, which was followed by a nearly 3-year suspension of space shuttle flights for reevaluation and testing, may have helped to accelerate the involvement of the private sector. Earlier, U.S. Government policy had supported the space shuttle as the sole method for space transport, and, accordingly, the private space industry had felt crowded out of launch service. However, the suspension of flights left the United States without serious launch capacity, leading NASA acting administrator William Graham to announce his support for developing a commercial launch industry and diversity in launch technology (Reynolds and Merges, 1998, p. 16). This change in policy from NASA, accompanied by new competition from Europe and the 1984 Commercial Space Launch Act, served to stimulate the development of a domestic commercial launch industry (Fuller, *et al.*, 2011), particularly for communication satellites.

By 1990, American manufacturing of communication satellites and satellite ground terminals totaled approximately \$6 billion annually (McLucas, 1991). Thus, from the policy shifts in the 1980s, came the opportunity for private expansion in the 1990s. Aside from the communications satellite industry, the launch sector grew most prominently, and two major forms of companies began to emerge: larger firms whose goal was to commercialize older and larger rocket technology and smaller start-ups attempting to develop new designs (Reynolds and Merges, 1988, p. 13). In addition to the growing opportunities for telecommunications services, most of these services were intended to be provided to and purchased by the government.

In 1990, then President George H. W. Bush signed into law the Launch Services Purchase Act.<sup>8</sup> The Act, in a complete reversal of the earlier Space Shuttle monopoly, ordered NASA to purchase launch services for its primary payloads from commercial providers whenever such services are required for its activities. This decision was also made in

### Key Legal and Policy Guidance on Commercial Space in the 2000s

**The Commercial Space Transportation Competitiveness Act of 2000 (P.L. 106405)** finds that *“a robust United States space transportation industry is vital to the Nation’s economic well-being and national security.”*

**U.S. Commercial Remote Sensing Policy (2003)** directed the U.S. Government to *“rely on commercial remote sensing space capabilities to the maximum practical extent.”*

**The White House Space Policy (2004)** states *“to exploit space to the fullest extent ... requires a fundamental transformation in U.S. space transportation capabilities”* and that *“the United States Government must capitalize on the entrepreneurial spirit of the U.S. private sector.”*

**The NASA Authorization Act of 2005 (P.L. 109155)** states that *“in carrying out the programs of the Administration, the Administrator shall ... work closely with the private sector, including by ... encouraging the work of entrepreneurs who are seeking to develop new means to send satellites, crew, or cargo to outer space.”*

**The White House Space Transportation Policy (2006)** states that U.S. government departments and agencies shall *“use U.S. commercial space capabilities and services to the maximum practical extent; purchase commercial capabilities and services when they are available in the commercial marketplace and meet United States Government requirements ...”*

the December 1986 Presidential decision directive “United States Space Launch Strategy” (Logsdon, *et al.* 1999).

Acknowledging the new growth of the private sector, the government continued to expand on its policy decisions in the decade before, issuing the *U.S. Commercial Space Guidelines* in 1991 to promote the policy of driving down market costs for private space through government investment (Chaddha, 2009). This initiative was made more far-reaching still with the 1998 Commercial Space Act, which removed the restriction on NASA’s ability to purchase services from private companies. Previously, NASA could purchase hardware from contractors but not things like wholesale launch services (Chaddha, 2009). This decision opened significant new markets for private launch companies. In addition, the act also promoted the future commercialization of the space launch, the demonstration of launch voucher programs, and the potential administration of commercial spaceports (Stone 2012). Also encouraging this decision was a more general interest in private space access — even space tourism — using small indigenously developed space access systems.

By 1995, the Office of Commercial Space Transportation, first set up in the DOT, was transferred to the FAA as AST, adding the authority to regulate reentry in 1998 (FAA, 2011). The year 1998 also saw release of the Commercial Development Plan for the ISS.<sup>9</sup> In 1996, the FAA issued the first commercial spaceport operators license to Spaceport Systems International in California (by 2012, the number would grow

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to eight FAA-licensed spaceports).

### The 2000s

The start of the millennium accelerated commercial space activity. In 2000, Congress passed the Commercial Space Transportation Competitiveness Act, authorizing further appropriations to both AST and the OSC (which had been around since 1998). The act also authorized a study on a “liability risk-sharing regime” for commercial space transport in the U.S.<sup>10</sup> In 2005, the DOC transferred its Space Commercialization office to the National Oceanographic and Atmospheric Administration (NOAA).<sup>11</sup>

In the private sector in 2004, Scaled Composites became the first company to receive a Reusable Launch Vehicle license from AST. Motivated by the reward of the \$10-million Ansari X Prize, Scaled also became the first private company to organize a commercial human launch that same year (FAA, 2010).

Also in 2004, the White House issued its *Vision for Space Exploration*, which included the goal of promoting international and commercial participation in exploration to further U.S. scientific, security, and economic interests. After taking office in the spring of 2005, NASA Administrator Mike Griffin stated his view and his direction to begin an official program office for commercial cargo and crew (Stone, 2012):

I believe that with the advent of the ISS, there will exist for the first time a strong, identifiable market for “routine” transportation service to and from LEO [low Earth orbit], and that this will be only the first step in what will be a huge opportunity for truly commercial space enterprise, inherent to the Vision for Space Exploration. I believe that the ISS provides a tremendous opportunity to promote commercial space ventures that will help us meet our exploration objectives and at the same time create new jobs and new industry.

The clearly identifiable market provided by the ISS is that for regular cargo delivery and return, and crew rotation especially after we retire the shuttle in 2010, but earlier should the capability become available. We want to be able to buy these services from American industry to the fullest extent possible. We believe that when we engage the engine of competition, these services will be provided in a

more cost-effective fashion than when the government has to do it. To that end, we have established a commercial crew/cargo project office, and assigned to it the task of stimulating commercial enterprise in space by asking American entrepreneurs to provide innovative, cost effective commercial cargo and crew transportation services to the space station.

NASA does not have a preferred solution. Our requirements will be couched, to the maximum extent possible, in terms of performance objectives, not process. Process requirements which remain will reflect matters of fundamental safety of life and property, or other basic matters. It will not be government “business as usual.” If those of you in industry find it to be otherwise, I expect to hear from you on the matter.

This and other statements by NASA leadership at the time, with the support of Congress and the National Space Policy, created their Human Space Flight Transition Plan in 2006. By 2006, NASA had also initiated the Commercial Off the Shelf (COTS) program, a public-private partnership to foster private space access to the ISS.<sup>12</sup> The year 2006 was also when NASA started using its other transaction authority privilege<sup>13</sup> specifically to stimulate development of private sector capabilities.<sup>14</sup> Referred to as a “funded Space Act Agreement (SAA),” it involved the transfer of appropriated funds to a domestic partner, such as a private company or a university, to accomplish an agency mission. These SAAs, which have continued to be used through today, differed from Federal Acquisition Regulation (FAR) contracts in that they did not include requirements that generally apply to government contracts entered into under the authority of the FAR. For example, under these agreements, partners are not required to comply with government contract quality assurance requirements (U.S. Government Accountability Office, 2011).

Further executive support for the commercial sector came from the 2006 U.S. National Space Policy. Again, NASA administrator Michael Griffin was a strong supporter.

I’d like for us to get to the point where we have the kind of private/public synergy in space flight that we have had for a hundred years in aviation ... I see a day in the not-very-distant future where instead of NASA buying a vehicle, we buy a ticket for our astronauts to ride to low Earth orbit, or

## Recent Legal and Policy Guidance on Commercial Space

**First Use of Funded Space Act Agreements (2006)** *jump-started the NASA COTS program.*

**The NASA Authorization Act of 2008 (P.L. 110422)** states that *"in order to stimulate commercial use of space, help maximize the utility and productivity of the International Space Station, and enable a commercial means of providing crew transfer and crew rescue services for the International Space Station, NASA shall make use of United States commercially provided International Space Station crew transfer and crew rescue services to the maximum extent practicable."*

**The National Space Policy of 2010 (PPD 4)** states that U.S. government departments and agencies shall *"purchase and use commercial space capabilities... to the maximum practical extent; actively explore the use of ... arrangements for acquiring commercial space goods; refrain from conducting United States Government space activities that preclude, discourage, or compete with U.S. commercial space activities, unless required by national security; actively promote the export of US commercially developed ... space goods and services."*

**The NASA Authorization Act of 2010** states that NASA *"... shall continue to support ... enabling the commercial space industry ... to develop reliable means of launching cargo and supplies to the ISS."*

a bill of lading for a cargo delivery to space station by a private operator. I want us to get to that point. (Milstein, 2009)

The 2010 National Space Policy (Office of Science and Technology Policy 2006; White House Office of the Press Secretary 2010; National Space Policy 2010) expanded government support for commercial activity, especially in the launch sector but also opened the door for many other experiments in commercial space.

## Today

In 2012, the first privately held firm — SpaceX (Space Exploration Technologies) — delivered cargo to the ISS under a fixed-price contract with NASA. It is expected that SpaceX and other firms will be able to take crew to the ISS by 2015.

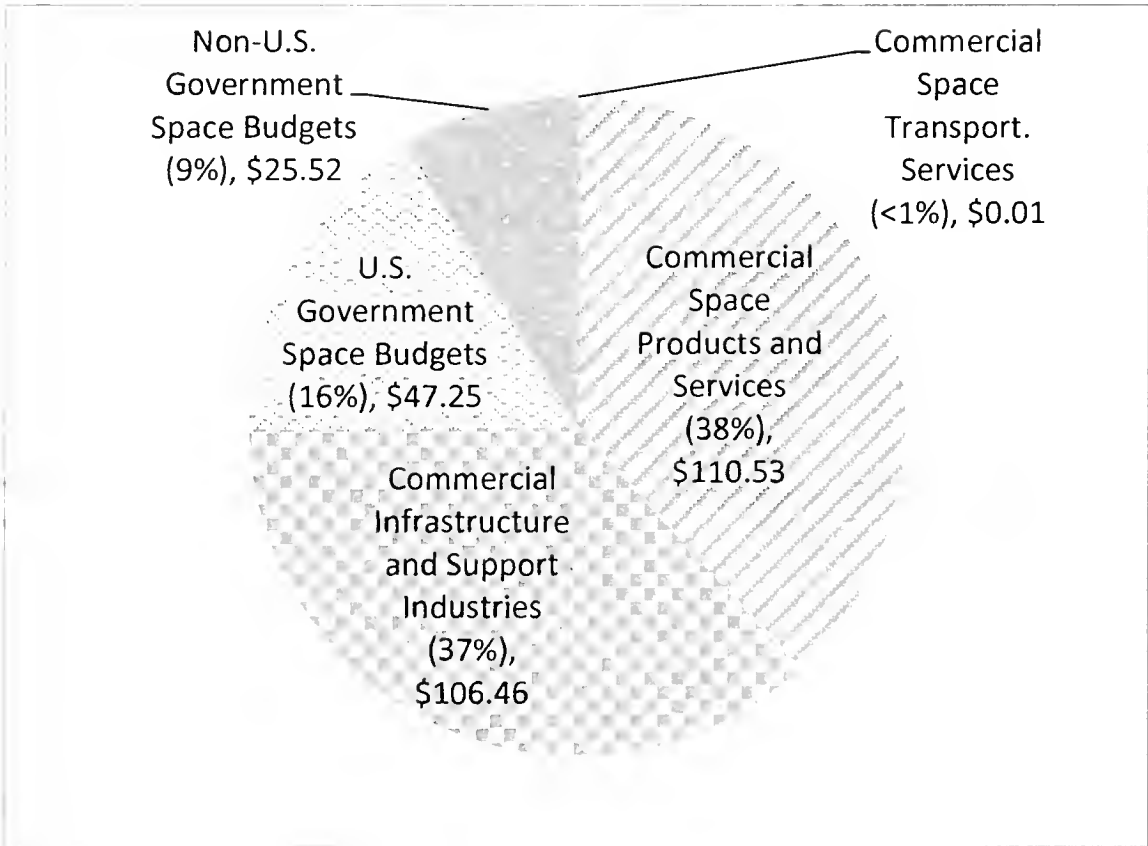
The government actively supports commercial efforts (with launch being one of the better known areas). NASA's Innovative Lunar Demonstrations Data (ILDD) program is challenging industry to demonstrate Earth-to-lunar surface flight system capabilities and test technologies, and DARPA's Phoenix program intends to develop and demonstrate technologies to harvest and reuse valuable components from retired, non-working satellites and demonstrate the ability to create new space systems at greatly reduced cost.

Outside of the government, several private and publicly held firms have ambitious plans. There is no formal count of the number of "commercial" activities, and new ventures are announced almost daily. In January 2013, for example, the Golden Spike

Company announced that it has plans to fly manned crews to the moon and back by 2020.<sup>15</sup> More recently, Deep Space Industries announced its intent to begin prospecting for asteroids suitable for mining by 2015 and by 2016 return asteroid samples to Earth.<sup>16</sup>

The private space sector today is large. In some applications, such as direct-to-home TV, the space sector is thriving. Three quarters of the world’s space related economic activity is commercial (see Figure 1), and space-related firms track the stock market and have outperformed the Standard & Poors (S&P) index in recent years (see Figure 2 where the Space Foundation Index is the middle line in the right-hand bar showing 2012).

**Figure 1.** Global Space Activity in 2011 (in billions of dollars)  
Total: \$289.77 Billion

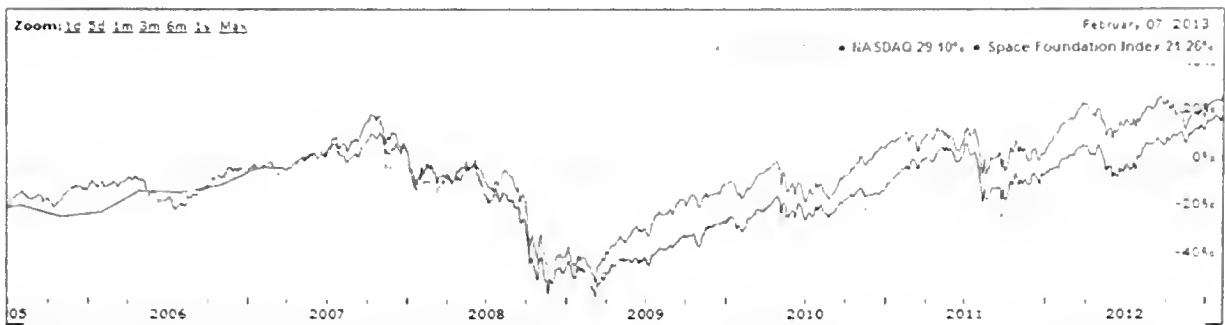


Source: The Space Foundation 2012b

**Summary**

By tracing the history of government policies, this paper demonstrates that while the space community is abuzz over recent developments and the growing potential of the commercial space sector, the reality is that the history of the role of non-governmental entities in space can trace its origins to a time well before the beginning of the space age.

**Figure 2.** Financial Performance of Publicly Held Space-Related Companies, Mid-2005 to 2012



Source: The Space Foundation 2012a

It also shows that, while many of the developments in commercial space appear to be recent (and certainly some of the successes in the launch sector are), the wheels of non-governmental activities in space were set into motion in the 1980s. What we see today is a culmination of almost 30 years of Legislative and Executive support for commercial activity. Its recent emergence may well be a “re-emergence.”

<sup>1</sup>This paper uses the National Space Policy definition of the term “commercial” space: “The term “commercial,” for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential non-governmental customers” (National Space Policy 2010). An analysis of the definition is conducted elsewhere (Science and Technology Policy Institute, 2013).

<sup>2</sup>However, perceptions of the private commercialization of space were increasingly reflected in the science fiction literature. Even the earliest space best seller, Jules Verne’s 1865 *From the Earth to the Moon*, clearly described space as a domain of the American military industrialists. Later, Robert Heinlein’s 1966 novel, *The Moon is a Harsh Mistress*, presented contrasting views of Lunar society and exploitation, and Kubrick’s 1969 work, *2001: A Space Odyssey*, had a prominent Pan American logo on the spacecraft.

<sup>3</sup>See, for example, *A Method of Researching Extreme Altitudes*, [http://www.clarku.edu/research/archives/pdf/ext\\_altitudes.pdf](http://www.clarku.edu/research/archives/pdf/ext_altitudes.pdf).

<sup>4</sup>However, AT&T's initial success did not guarantee its market dominance, as was quickly evidenced by its loss of a major early satellite contract, the Relay program, to rival RCA. To win the contract, RCA leveraged its previous experience building a variety of military satellite systems (particularly the Television Infrared Observation Satellite [TIROS] weather satellites) as well as fears about AT&T's potential telecommunications monopoly.

<sup>5</sup>The exact relationship between COMSAT, Intelsat, and the private and public sectors for communication satellites was nuanced and changed over time. Appendix A to this report presents a more thorough case study on the growth, development, and commercialization of communication satellites.

<sup>6</sup>See "Perception vs. Reality in NASA's Commercial Crew and Cargo Program," <http://www.thespacereview.com/article/2166/1>.

<sup>7</sup>Congressional interest in commercial space continues to the day. Most recently (June 20, 2012), the U.S. Senate Subcommittee on Science and Space held a hearing on the "Risks, Opportunities, and Oversight of Commercial Space." [http://commerce.senate.gov/public/index.cfm?p=Hearings&ContentRecord\\_id=c3ae3f1c-f1b9-47a1-8eef-5013d1d68f91&ContentType\\_id=14f995b9-dfa5-407a-9d35-56cc7152a7ed&Group\\_id=b06c39af-e033-4cba-9221-de668ca1978a&MonthDisplay=6&YearDisplay=2012](http://commerce.senate.gov/public/index.cfm?p=Hearings&ContentRecord_id=c3ae3f1c-f1b9-47a1-8eef-5013d1d68f91&ContentType_id=14f995b9-dfa5-407a-9d35-56cc7152a7ed&Group_id=b06c39af-e033-4cba-9221-de668ca1978a&MonthDisplay=6&YearDisplay=2012)

<sup>8</sup>See "Launch Services Purchase Act of 1990," <http://forum.nasaspaceflight.com/index.php?topic=20497.0>, <http://archive.spacefrontier.org/commercialspace/lspalaw.txt>, <http://uscode.house.gov/download/pls/51C101.txt>.

<sup>9</sup>See "Commercial Development Plan for the International Space Station," <http://history.nasa.gov/31317.pdf>

<sup>10</sup>Only 4 years later, Congress amended the original Commercial Space Launch Act to establish a regulatory framework specifically intended for human spaceflight. Provisions of the amendments included the concept of "informed consent" for space tourists as well as a new experimental launch test permit (FAA, 2010).

<sup>11</sup>See "Departmental Authority," <http://www.space.commerce.gov/about/doo.shtml>.

<sup>12</sup>Out of this effort came the first private space support missions flown to the ISS, by the Dragon spacecraft (National Research Council, 2012).

<sup>13</sup>Granted it through P.L. 85-568, § 203.

<sup>14</sup>See "NASA Policy Directive: Authority to Enter into Space Act Agreements," <http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=1050&s=11>; also explained at [http://www.americanbar.org/content/dam/aba/administrative/science\\_technology/10\\_11\\_11\\_spaceact\\_ppt.authcheckdam.pdf](http://www.americanbar.org/content/dam/aba/administrative/science_technology/10_11_11_spaceact_ppt.authcheckdam.pdf)



<sup>15</sup>See Golden Spike Company website, <http://goldenspikecompany.com/>.

<sup>16</sup>See Deep Space Industries website, <http://deepspaceindustries.com/>.

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## Bio

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# Estimating the Climate Impact of Transportation Fuels: Moving Beyond Conventional Lifecycle Analysis Toward Integrated Modeling Systems Scenario Analysis

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## Abstract

As commonly employed, life-cycle analysis (LCA) cannot accurately represent the climate impacts of complex systems such as those involved in making and using biofuels for transportation. LCA generally is linear, static, highly simplified, and tightly circumscribed. The real world, which LCA attempts to represent, is none of these. Among LCA's major deficiencies are: its failure to explicitly specify alternative courses of action; its incomplete accounting for price effects; its incomplete treatment of land-use change; its neglect of the nitrogen cycle; and its omission of climate-impact modeling steps and climate-relevant pollutants. In order to better represent the impacts of complex systems such as those surrounding biofuels, analysts need a different tool — one that has the central features of LCA, but not the limitations. I propose as a successor to LCA a method of analysis that combines integrated assessment modeling, life-cycle analysis, and scenario analysis. I call this method integrated modeling systems and scenario analysis (IMSSA). IMSSA uses dynamic, nonlinear, feedback-modulated representations of energy, economic, ecological, and technological systems in order to estimate the physical and economic impacts of policies or actions, particularly those related to biofuels.

## Introduction

**FOR SEVERAL DECADES** analysts have used a tool called “lifecycle analysis” (LCA) to estimate the environmental and energy impacts of a variety of production and consumption processes. The distinguishing feature of LCA is that it aggregates impacts from all of the activities involved in producing, distributing, using, and disposing of a product. For

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the past 20 years, as concerns about climate change have grown and the search for alternatives to fossil fuels has intensified, LCA has been increasingly used to estimate emissions of “greenhouse gases” (GHGs) from the use of a wide range of alternative transportation fuels.

However, as commonly used, LCA cannot accurately represent the impacts of complex energy systems, such as those involved in making and using biofuels for transportation. LCA generally is linear, static, highly simplified, and tightly circumscribed. The real world, which LCA attempts to represent, is none of these (Plevin *et al.*, 2013). In order to better represent the impacts of complex systems such as biofuels, we need a different tool — one that has the central features of LCA, but not the limitations.

This paper discusses the limitations of conventional LCA and then proposes a new modeling system called Integrated Modeling Systems and Scenario Analysis (IMSSA), which combines integrated assessment modeling, lifecycle analysis, and scenario analysis. Given the scientific consensus that the use of fossil fuels is causing rapid and unprecedented climate change, and the finding by the Intergovernmental Panel on Climate Change (IPCC) that fossil-fuel use must be drastically curtailed to avoid dangerous warming above 2 degrees Celsius (IPCC, 2013), I discuss the commonly-used LCA and the newer IMSSA in the context of understanding the climate impact of alternative transportation fuels in general and biofuels in particular. I focus on biofuels because bioenergy systems are especially complex and challenging to model.

### **Background and General Critique of LCA**

Current lifecycle analyses of GHG emissions from transportation fuels can be traced back to “net energy” analyses. These LCAs were done in the late 1970s and early 1980s in response to the oil crises of 1973 and 1979, which motivated a search for alternatives to petroleum. These LCAs were relatively straightforward, generic, partial “engineering” analyses of the amount of energy required to produce and distribute energy feedstocks and finished fuels. Their objective was to compare alternatives to conventional gasoline and diesel fuel according to total lifecycle use of energy, fossil fuels, or petroleum.

In the late 1980s, analysts, policy makers, and the public began to worry that burning coal, oil, and gas would affect global climate. Interest in alternative transportation fuels, which had subsided on account of low oil prices in the mid-1980s, was renewed. Motivated now by global as

well as local environmental concerns, engineers again analyzed alternative transportation lifecycles. Unsurprisingly, they adopted the methods of their “net-energy” engineering predecessors, except that they took the additional step of estimating net carbon dioxide (CO<sub>2</sub>) emissions, based on the carbon content of fuels.

By the early 1990s, analysts had added two other greenhouse gases, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), weighted by their “Global Warming Potential” (GWP), to come up with a metric known as lifecycle CO<sub>2</sub>-equivalent (CO<sub>2</sub>e) emissions for alternative transportation fuels. (The section “LCA Deficiency 5” discusses the GWP metric in more detail.) Today, most LCAs of transportation and global climate are not appreciably different in general method from those analyses done in the early 1990s.<sup>1</sup> Although various analysts have made different assumptions and used slightly different specific estimation methods — and as a result have come up with a variety of answers — only recently have a number of researchers begun to seriously question the general validity of this method that has been handed down to them (Plevin *et al.*, 2013).

In principle, LCAs of transportation and climate are much broader than the net-energy analyses from which they were derived. Hence, they have all of the shortcomings of net-energy analyses plus many more. For example, the original net-energy analyses of the 1970s and 80s can be criticized for failing to include economic variables on the grounds that any alternative-energy policy would affect prices and hence uses of all major sources of energy. Based on this criticism, the lifecycle GHG analyses that followed can be criticized on the same grounds, but even more cogently. (In the case of lifecycle GHG analyses we care about any economic effect anywhere in the world, whereas in the case of net-energy analysis we care about economic effects only insofar as they affect the country of interest.) Beyond this, lifecycle GHG analysis in principle encompasses additional areas of data (such as emission factors) and, more importantly, additional large and complex systems (e.g., the nitrogen cycle, the hydrologic cycle, global climate), all of which introduce considerable additional uncertainty.

The upshot is that traditional or conventional LCAs of transportation and climate are not built on a carefully derived, broad, theoretically and historically solid foundation, but rather are ad-hoc extensions of a method — net-energy analysis — that was itself incomplete and theoretically ungrounded to be valid on its own terms. Therefore, this method cannot reasonably be extended to the considerably broader and more complex problem of estimating the global climate

impacts of transportation energy policies. Today, lifecycle analyses of GHG emissions from transportation fuels usually are consistent with LCA guidelines established by the International Organization for Standardization<sup>2</sup> (ISO). The ISO guidelines properly address only a few of the deficiencies discussed here.

The broader LCA community is beginning to recognize the need for a more comprehensive integrated modeling approach to traditional LCA problems. In this respect, Feng *et al.* (2008) discuss “system-wide accounting,” Pehnt *et al.* (2008) discuss “consequential environmental systems analysis,” and Finnveden *et al.* (2009) discuss “environmental systems analysis using life cycle methodology.” At a general conceptual level, all of these approaches and the one proposed here, are a version of the well established field of “integrated assessment modeling” (e.g., Parson and Fisher-Vanden, 1997; Guinée *et al.*, 2011; and Weidema and Ekvall, 2009).

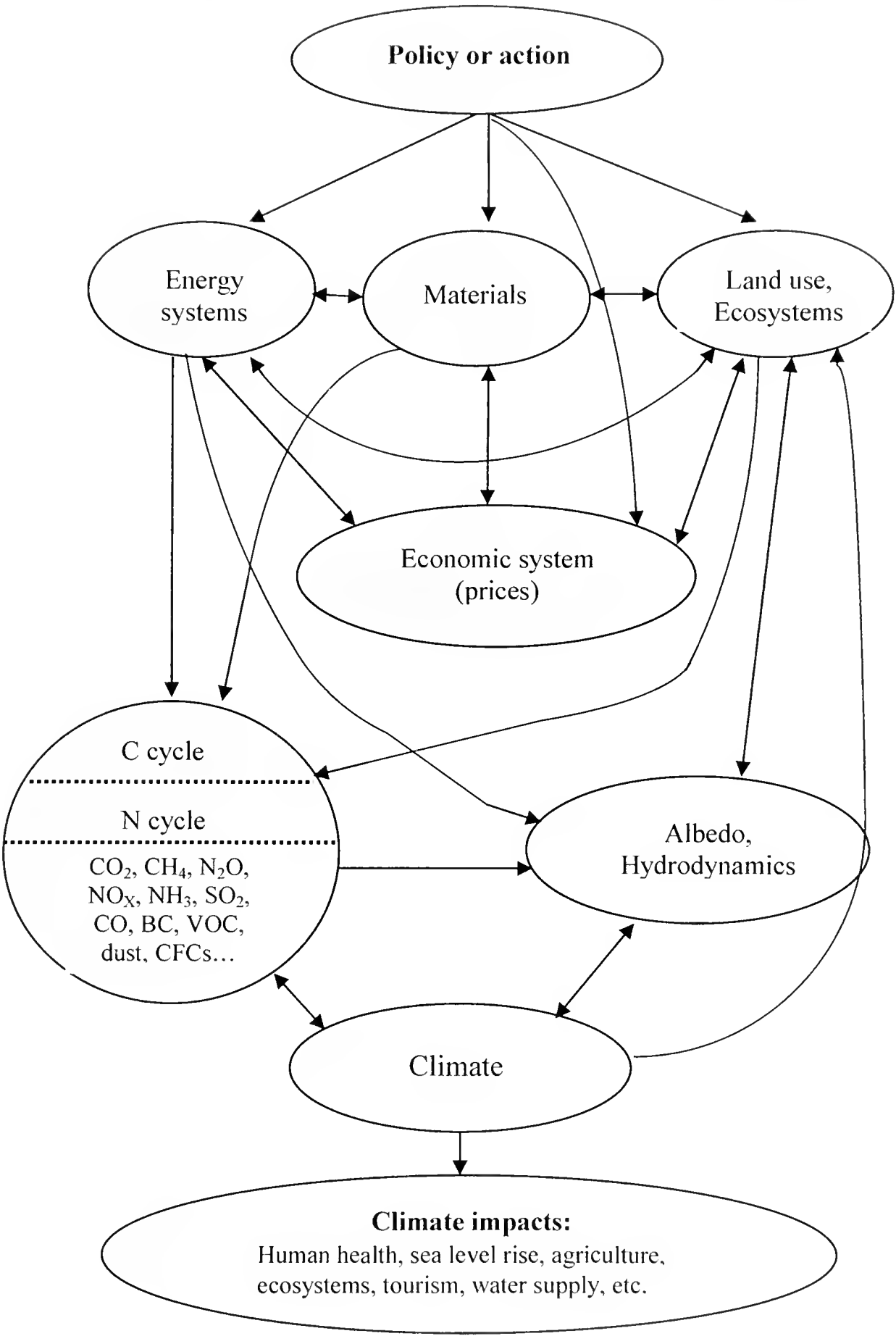
### **Comparison of Conventional LCA with IMSSA**

This paper proposes something similar to integrated assessment modeling (IAM), but with more emphasis on the systems integration and scenario analysis; hence the term, “Integrated Modeling Systems Scenario Analysis” (IMSSA). Figures 1 and 2 delineate the modeling structure in IMSSA and conventional LCA, and Table 1 compares conventional LCA with IMSSA.

In principle, lifecycle analyses of GHG emissions from transportation fuels are meant to help us understand the impact on global climate of some proposed transportation policy or action (“policy/action”). I refer generally to the impacts of the policy/action on “environmental systems.” Figure 1 shows that IMSSA starts with the specification of a policy/action and ends with the impacts on environmental systems. In between are a series of steps that constitute the conceptual components of the model.

The impact of climate change — the ultimate output of interest — is a function of the dynamic state of the climate system. Importantly, however, the climate system is influenced by a wide range of emissions beyond the three commonly considered in transportation LCAs (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) and by other factors such as albedo (reflectivity). Emissions and non-emission factors, in turn, are affected by energy systems, material systems, land-use systems, and natural ecosystems. All of these are affected by, and in some cases affect, policies and economic systems.

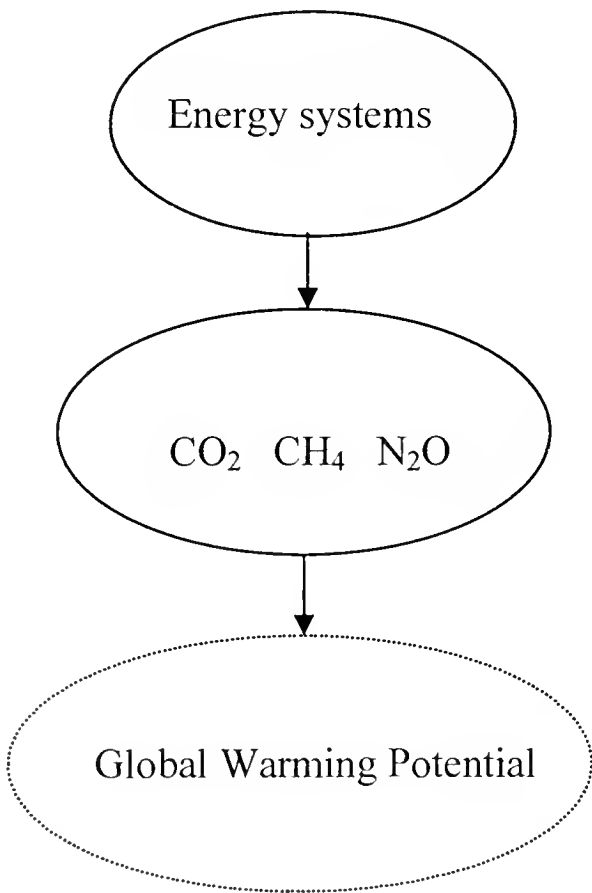




**Figure 1.** Representation of an ideal model (IMSSA)

Indeed, as illustrated in Figure 1, there are many important feedbacks, especially between energy systems, material systems, land-use and ecosystems, economic systems, non-emission factors, and climate systems.

However, conventional LCA does not capture this complexity (see Figure 2) and instead usually represents a simplistic no-feedback system that considers only energy use, emissions of three GHGs, and a simplified measure of climate, the Global Warming Potential. Some LCAs also include the lifecycle of materials, and recently some LCAs have added a simple partial treatment of land-use change (LUC). Thus, as indicated in Table 1 comparing the two approaches, conventional LCA lacks explicit representations of policy, economic systems, and climate impacts. It also has simplified or incomplete treatments of the nitrogen cycle, land-use change and ecosystems, the climate system, and GHGs other than CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O.<sup>3</sup>



**Figure 2.** Representation of conventional LCA

Table 1. Comparison of conventional LCA with IMSSA

| Component in IMSSA        | Treatment in Conventional LCA   |
|---------------------------|---|
| Policy analysis           | No policy analysis in conventional LCA, which simply assumes that one set of activities replaces another.   |
| Energy systems            | Energy systems typically are well represented as input-output relationships in conventional LCA.  |
| Materials systems         | Some conventional LCAs consider materials flows.  |
| Land-use and ecosystems   | Most conventional LCAs ignore land-use and ecosystems or treat them simplistically.   |
| Economic effects (prices) | Conventional LCAs do not model price changes and their effects.   |
| Carbon cycle              | Conventional LCA does not have a formal model of the carbon cycle.  |
| Nitrogen cycle            | Conventional LCA does not have a formal model of the nitrogen cycle.  |
| Air pollutants            | Conventional LCAs count most but not all sources of CH <sub>4</sub> and N <sub>2</sub> O, and typically omit (as GHGs) CO, NO <sub>x</sub> , SO <sub>x</sub> , PM, O <sub>3</sub> , and more. |
| Albedo, hydrodynamics     | Not included in conventional LCA.   |
| Climate system            | GWPs are simplistic and do not capture several important aspects of climate change.   |
| Impacts of climate change | Conventional LCA does not model impacts of climate change.  |

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## LCA Deficiency 1: Failure to Explicitly Specify Alternative Courses of Action

Conventional LCAs of transportation and climate change typically do not analyze a specific policy or even posit a specific question for analysis. Instead, the implicit questions of conventional LCA must be inferred from the conclusory statements and the methods of analysis. In transportation-fuel LCAs, the conclusory statements typically are of the sort:

“The use of fuel  $F$  in light-duty vehicles has  $X\%$  more [or less] emissions of CO<sub>2</sub>e GHG emissions per mile than does the use of gasoline in light-duty vehicles.”

The method of analysis is illustrated in Figure 2 which indicates that, in conventional LCA, CO<sub>2</sub>e emissions are equal to emissions of CO<sub>2</sub> plus equivalency-weighted emissions of non-CO<sub>2</sub> gases, where the equivalency weighting usually is done with respect to radiative forcing over a 100-year time period. Given this, we can infer that the implicit question being addressed by most conventional LCAs of GHG emissions in transportation is something like:

What would happen to an incomplete measure of radiative forcing over the next 100 years if we simply replace the limited set of activities that we have defined to be the “gasoline lifecycle” with the limited set of activities that we have defined to be the “fuel  $F$  lifecycle,” with no other changes occurring in the world?

The problem here is that this question is irrelevant in these two respects, discussed in more detail in later sections:

- i. No actions that anyone can take in the real world will have the net effect of just replacing the narrowly defined set of ‘gasoline activities’ with the narrowly defined set of ‘fuel- $F$  activities,’ and
- ii. We do not care about radiative forcing per se (let alone an *incomplete* measure of radiative forcing), and our concern is not limited to 100 years; rather, we care about the actual impacts of climate change over a very long time period of time.

Because conventional LCAs do not evaluate explicit, realistic, specific policies/actions, it is difficult if not impossible to relate the results of conventional LCAs to any actual policies/actions in the real world.

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## **LCA Deficiency 2: Incomplete (or No) Accounting for Price Effects**

All energy and environmental policies affect prices. Changes in prices affect consumption, and hence output. Changes in consumption and output change emissions. In the real world, price effects are ubiquitous. They occur in every market affected directly or indirectly by transportation fuels — the market for agricultural commodities, the market for fertilizer, the market for oil, the market for steel, the market for electricity, the market for new cars — and often are important.

Although most recent conventional LCAs do not account for price effects, the broader economic modeling community is beginning to analyze the role of price effects in LCA. As discussed under the section, “LCA Deficiency 3,” a few recent analyses have estimated how changes in biofuel production change the prices of agricultural commodities and thereby change the use of land, which leads to the emission or sequestration of carbon. Economic modelers also have just begun to examine some aspects of one of the most important potential price effects: the impact of any non-petroleum alternative on the price of oil.

### ***Price Effects Related to Oil Use***

In general, the substitution of any non-petroleum fuel for gasoline will contract the demand for gasoline, which in turn will contract demand for crude oil, which probably will reduce the price of crude oil. This reduction in the world price of oil will stimulate increased consumption of petroleum products for all end uses worldwide. The increased use of petroleum products will increase all of the energy and environmental impacts of petroleum use, including climate change impacts. Hence, the use of non-petroleum alternative fuels can cause increases in GHG emissions in the petroleum sector via price feedbacks.

Economic theory suggests that the interconnections are even more complex. For example, a large price subsidy, such as the subsidy enjoyed by corn ethanol, ultimately causes a loss of social welfare on account of output being suppressed below optimal levels due to the inefficient use of (tax) resources. This loss of output probably is associated ultimately with lower GHG emissions. Thus, in this case, a subsidy policy may have countervailing effects: On the one hand, there will be an increase in GHG emissions caused by increased use of petroleum due to the lower price of oil due to the substitution of ethanol. On the other hand, there will be a decrease in GHG emissions due to the reduction in output caused by the

subsidy. By contrast, a research and development (R&D) policy that succeeds in bringing to market a new low-social-cost fuel will, on account of the more efficient use of energy resources, unambiguously improve social welfare.

Research on price effects related to oil use is relatively recent (Delucchi, 2005; Dixon *et al.*, 2007; Hochman *et al.*, 2010; Rajagopal *et al.*, 2011), and is consistent with the theoretical expectations discussed above. For example, Hochman *et al.* (2010) quantify the effects of biofuels on global crude oil markets, and find that the introduction of biofuels reduces international fuel prices by between 1.07 and 1.10% and increases global fuel consumption by 1.5 to 1.6% (p. 112).

### ***Other Price Effects***

Price effects also are likely to be important in cases of joint production, where one process and one set of inputs inseparably produce more than one marketed output. It is well known that corn-ethanol plants, for example, produce commodities other than ethanol. A policy promoting ethanol therefore is likely to result in more output of these other goods, as well as more production of ethanol. The proper approach is to model the market for the other goods to determine, in the final equilibrium, what changes in consumption and production mediated by price changes occur in the world with the ethanol policy. The same issue of joint production also arises in petroleum refineries and in other processes in fuel lifecycles.

Price changes can have a large number of what are likely to be relatively minor effects. For example, different life cycles use different amounts of steel and hence have different effects on the price and thereby the use of steel in other sectors. Although it might be reasonable to presume that in these cases the associated differences in emissions of GHGs are relatively small, sometimes many quite small individual effects add up (rather than cancel each other). Therefore, it would be ideal for lifecycle analysts to investigate a few classes of these apparently minor price effects.

### **LCA Deficiency 3: Incomplete Treatment of Land-Use Change**

As indicated in Figure 1, changes in land-use can affect climate in several ways. They affect:

- the flows of carbon between the atmosphere and soil and plants;
- climate-relevant physical properties of land, such as its albedo;

- the nitrogen cycle which, in turn, can affect climate in several ways — for example, via production of  $\text{N}_2\text{O}$  or by affecting the growth of plants which, in turn, affects carbon- $\text{CO}_2$  removal from the atmosphere via photosynthesis;
- the hydrologic cycle, which again affects climate in several ways; and
- the fluxes of other pollutants that can affect climate, such as  $\text{CH}_4$ , volatile organic compounds, and aerosols.

### ***CO<sub>2</sub> Emission from Land-Use Change***

Conceptually, an ideal model of the climate impact of changes in carbon emissions due to land-use change (LUC) caused by bioenergy policies has several streams, listed in Table 2. The modeling begins with an estimate of  $\text{CO}_2$  emissions from LUC based on the difference, over time, between ecosystem carbon content in a “no bioenergy program” baseline case compared with ecosystem carbon content in a “with bioenergy program” case (where “bioenergy program” refers to a specific program and need not encompass all bioenergy in the world). It ends with an estimate of the differences in climate impacts between the “with bioenergy” and “without bioenergy” cases.

In a cost-benefit or economic framework, the impacts would be monetized and discounted to their present value. The (monetized and discounted) stream of climate-change-impact differences — associated ultimately with the year-by-year differences in land uses between the “no-bioenergy-program” and “with-bioenergy-program” cases — would represent the climate-change impact of  $\text{CO}_2$  emissions from LUC resulting from a bioenergy program.

Ideally, this modeling would be part of a comprehensive analysis of the climate impacts of bioenergy programs, which would include, in addition to the impacts of  $\text{CO}_2$  emissions from LUC just described, two other general kinds of impacts:

- the climate impacts of LUC *other* than those resulting from  $\text{CO}_2$  emissions (e.g., changes in albedo; see Cherubini *et al.*, 2012); and
- the climate impacts from the rest of the bioenergy production-and-use chain.

The value of all of these other impacts would be added to the value of the impacts of the CO<sub>2</sub> emissions from LUC to produce a comprehensive measure of the climate impact of a bioenergy program.

While a few recent LCA studies (e.g., Hertel *et al.*, 2010a, 2010b; Plevin *et al.*, 2010; Searchinger *et al.*, 2008) have addressed part of Stream 1 in Table 2 (economic modeling of LUC), the treatment of this stream is incomplete. And no published peer-reviewed LCA study has addressed the other four streams properly. Most importantly, no LCA work apart from Delucchi (2011) has a conceptual framework that properly represents all of the following: the reversion of land uses at the end of the biofuels program; the actual behavior of emissions and climate over time; and the treatment of future climate-change impacts relative to present impacts.

### ***Biogeophysical Impacts of Land-Use Change***

Changes in land use and vegetation can change physical parameters, such as albedo and evapotranspiration rates, which directly affect the absorption and disposition of energy at the surface of the earth, and thereby affect local and regional temperatures (Bala *et al.*, 2007; Cherubini *et al.*, 2012; Lobell *et al.*, 2006; Marland *et al.*, 2003). Changes in temperature and evapotranspiration can affect the hydrologic cycle (Georgescu *et al.*, 2009) which, in turn, can affect ecosystems and climate in several ways, such as via: the direct radiative forcing of water vapor, evapotranspirative cooling, cloud formation, or rainfall. This affects the growth and hence carbon sequestration by plants (Bala *et al.*, 2007; Marland *et al.*, 2003; Pielke, 2005).

In some cases, the climate impacts of changes in albedo and evapotranspiration due to LUC appear to be of the same order of magnitude, but of the opposite sign as the climate impacts that result from the associated changes in carbon stocks in soil and biomass due to LUC. For example, Bala *et al.* (2007) find that “the climate effects of CO<sub>2</sub> storage in forests are offset by albedo changes at high latitudes, so that from a climate change mitigation perspective, projects promoting large-scale afforestation projects are likely to be counterproductive in these regions” (p. 6553). This suggests that the incorporation of these biogeophysical impacts into biofuel LCAs could significantly change the estimated climate impact of biofuel policies.



**Table 2.** Environmental and economic modeling of LUC: Hierarchy of streams in the representation of the climate impacts of bioenergy policies due to CO<sub>2</sub> emissions based on changes in land use

| Stream                                 | Delineation of Stream   |
|--|---|
| 1. Program actions                     | <p>Prices, yields, supply curves, and land uses can change over time, year-by-year, in the “with bioenergy program” case compared to the “no bioenergy program” case.</p> <p>These changes occur at the end of the bioenergy program as well as at the beginning.</p>   |
| 2. Emissions                           | <p>Each change in land use (in each year) generates its own time series of changes in carbon emissions.</p> <p>For example, a change in land use in any year <math>T</math> initiates a process of carbon emission or sequestration that can continue for many years after <math>T</math>.</p> <p>These emission streams occur at the end of the program as well as at the beginning.</p>   |
| 3. Concentration and radiative forcing | <p>Each change in carbon emission or sequestration (in each year) generates its own time series of changes in CO<sub>2</sub> concentration (atmospheric carbon stocks) and radiative forcing.</p> <p>For example, an emission of carbon from soils in year <math>T+x</math> (due ultimately to LUC in year <math>T</math>) will generate an atmospheric CO<sub>2</sub> concentration and decay profile and associated radiative-forcing effects that extend for many decades beyond <math>T+x</math>.</p> |
| 4. Climate change                      | <p>Any change in radiative forcing in any year will generate a stream of climate changes, the lag between radiative forcing (Stream #3) and climate change (Stream #4) being due mainly to the thermal inertia of the oceans.</p>   |
| 5. Impacts                             | <p>Any change in climate, in any year (Stream #4), can impact people and ecosystems for many years (e.g., by changing the incidence of chronic diseases).</p>   |

There also are interactive and feedback effects between climate change, land use, and water use. For example, changes in precipitation and evapotranspiration (due to climate change) will affect groundwater levels (Bovolo *et al.*, 2009) and cropping patterns, which in turn will give rise to other environmental impacts, including feedback effects on climate change. People in less wealthy countries may be most vulnerable to these changes because they have less capacity to mitigate or adapt to impacts on groundwater (Bovolo *et al.*, 2009).

#### **LCA Deficiency 4: Neglect of the Nitrogen Cycle**

Anthropogenic inputs of nitrogen to the environment, such as from the use of fertilizer or the combustion of fuels, can disturb aspects of the global nitrogen cycle and have a wide range of environmental impacts. These include: eutrophication of lakes and coastal regions; fertilization of terrestrial ecosystems; acidification of soils and water bodies; changes in biodiversity; respiratory disease in humans; ozone damages to crops; and changes to global climate (Fowler *et al.*, 2013; Galloway *et al.*, 2003; Mosier *et al.*, 2002; Vitousek *et al.*, 1997). Galloway *et al.* (2003) depict this as a “nitrogen cascade” in which “the same atom of Nr [reactive N, such as in NO<sub>x</sub> or NH<sub>y</sub>] can cause multiple effects in the atmosphere, in terrestrial ecosystems, in freshwater and marine systems, and on human health” (p. 341; brackets added). As a result, nitrogen emissions to the atmosphere, as NO<sub>x</sub>, NH<sub>y</sub>, or N<sub>2</sub>O, can contribute to climate change through complex physical and chemical pathways that affect the concentration of ozone (O<sub>3</sub>), CH<sub>4</sub>, N<sub>2</sub>O, CO<sub>2</sub> and aerosols:

- i. NO<sub>x</sub> participates in a series of atmospheric chemical reactions involving carbon monoxide (CO), volatile organic compounds (VOCs), H<sub>2</sub>O, OH<sup>-</sup>, O<sub>2</sub>, and other species that affect the production of tropospheric ozone, a powerful GHG as well as an urban air pollutant.
- ii. In the atmospheric chemistry mentioned in *i*), NO<sub>x</sub> affects the production of the hydroxyl radical, OH, which oxidizes methane and thereby affects the lifetime of CH<sub>4</sub>.
- iii. In the atmospheric chemistry mentioned in *i*), NO<sub>x</sub> affects the production of sulfate aerosol which, as an aerosol, has a net *negative* radiative forcing and thereby a beneficial effect on climate (IPCC, 2007), on the one hand. On the other hand, it adversely affects human health.

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- iv.  $\text{NH}_Y$  and nitrate from  $\text{NO}_X$  deposit onto soils and oceans and then eventually re-emit N as  $\text{N}_2\text{O}$ ,  $\text{NO}_X$ , or  $\text{NH}_Y$ . Nitrate deposition also affects soil emissions of  $\text{CH}_4$ .
  - v.  $\text{NH}_Y$  and nitrate from  $\text{NO}_X$  fertilize terrestrial and marine ecosystems and thereby stimulate plant growth and sequester carbon in nitrogen-limited ecosystems.
  - vi.  $\text{NH}_Y$  and nitrate from  $\text{NO}_X$  form ammonium nitrate which, as an aerosol, has a net *negative* radiative forcing (IPCC, 2007), on the one hand, and thereby a beneficial effect on climate. On the other hand, this adversely affects human health.
  - vii. As deposited nitrate, N from  $\text{NO}_X$  can increase acidity and harm plants and thereby reduce C- $\text{CO}_2$  sequestration.

Even though the development of many kinds of biofuels will lead to large emissions of  $\text{NO}_X$ ,  $\text{N}_2\text{O}$ , and  $\text{NH}_Y$ , virtually all lifecycle analyses of  $\text{CO}_2$ -equivalent GHG emissions from biofuels ignore all N emissions and the associated climate effects except for the effect of N fertilizer on  $\text{N}_2\text{O}$  emissions. (Some preliminary, more comprehensive estimates are provided in Delucchi, 2003, 2006.)

Even in the broader literature on climate change there has been relatively little analysis of the climate impacts of N emissions, because as Fuglestad *et al.* (2003) note, “GWPs for nitrogen oxides ( $\text{NO}_X$ ) are amongst the most challenging and controversial” (p. 324). Shine *et al.* (2005) estimate the global warming impacts of the effect of  $\text{NO}_X$  on  $\text{O}_3$  and  $\text{CH}_4$ , focusing on regional differences (*i* and *ii* above). However, they merely mention and do not quantify the effect of  $\text{NO}_X$  on nitrate aerosols (*vi* above) and do not mention the other impacts (*iii*, *iv*, *v*, and *vii*). Prinn *et al.* (2005) and Brakkee *et al.* (2008) estimate effects *i* and *ii*. These studies, along with the preliminary work by Delucchi (2003, 2006) suggest that the climate impacts of perturbations to the N cycle by the production and use of biofuels could be comparable to the impacts of LUC.

### **LCA Deficiency 5: Omission of Climate-Impact Modeling Steps and Climate-Relevant Pollutants**

The ultimate objective of LCAs of GHG emissions in transportation is to determine the effect of a particular policy on global climate and the impact of global climate change on quantities of interest (e.g., human welfare). This requires a number of modeling steps beyond the economic and environmental modeling discussed above. These steps,

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discussed in Table 2, involve estimating relationships between policies and emissions, emissions and concentration, concentration and radiative forcing, radiative forcing and temperature change, and temperature change and climate impacts for all climate-relevant pollutants. Conventional LCAs omit or characterize poorly most of these steps and omit most climate-relevant pollutants.

Conventional LCAs do not estimate the climate-change impacts of GHG emissions from transportation fuels, but rather use the quantity called “Global Warming Potential” to convert emissions of CH<sub>4</sub>, N<sub>2</sub>O, and CO<sub>2</sub> into a common index of temperature change. GWPs tell us the grams of CH<sub>4</sub> or N<sub>2</sub>O that produce the same integrated radiative forcing, over a specified period of time, as one gram of CO<sub>2</sub>, given a single pulse of emissions of each gas (IPCC, 2007). Typically, analysts use GWPs for a 100-year time horizon.

There are several problems with the GWP metric (Bradford, 2001; Fuglestvedt *et al.*, 2003; Godal, 2003; IPCC, 2007; Manne and Richels, 2001; O’Neill, 2003):

- First, society cares about the impacts of climate change, not about radiative forcing per se, and changes in radiative forcing are not linearly correlated with changes in climate impacts.
- Second, the method for calculating the GWPs involves several unrealistic simplifying assumptions, which can be avoided relatively easily in a more realistic, comprehensive CO<sub>2</sub>-equivalency metric.
- Third, by integrating radiative forcing from the present day to 100 years hence, the GWPs in effect give a weight of 1.0 to every year between now and 100 and a weight of 0.0 to every year beyond 100, which does not reflect how society makes tradeoffs over time. (A more realistic treatment would use continuous discounting [Bradford, 2001; Delucchi, 2011].)
- Fourth, the conventional method omits several gases and aerosols that are emitted in significant quantities from biofuel lifecycles and can have a significant impact on climate, such as ozone precursors (VOCs, CO, NO<sub>x</sub>), ammonia (NH<sub>3</sub>), sulfur oxides (SO<sub>x</sub>), black carbon (BC), and other aerosols (IPCC, 2007).

A better approach is to use an equivalency metric that equilibrates the present-dollar value of the impacts of climate change from a unit emission of gas  $i$  with the present-dollar value of the impacts of climate change from a unit emission of CO<sub>2</sub>. Ideally, these present-value metrics would be derived from runs of climate-change models for generic, but explicitly delineated, policy scenarios.

### **Toward a More Comprehensive Model: IMSSA**

If researchers want the results of their analyses of the climate-change impacts of transportation policies to be interpretable and relevant, their models must be designed to address clear and realistic questions. In the case of LCA comparing the energy and environmental impacts of different transportation fuels and vehicles, the questions and issues must be of the sort: “What would happen to [some measure of energy use or emissions] if somebody did X instead of Y?” where X and Y are specific and realistic alternative courses of action. These alternative courses of action may be related to public policies or to private-sector market decisions, or both. In any event, LCA models must be able to properly trace out all of the differences — political, economic, technological, environmental — between the world with X and the world with Y.

So, rather than ask, “What would happen if we replaced [one very narrowly defined set of activities] with [another narrowly defined set of activities]?” and then use an engineering process-life-cycle model to answer this (misplaced) question. Instead, we should ask, “What would happen in the world if we were to take one realistic course of action rather than another?” And then use an integrated economic, environmental, and engineering model — IMSSA — to answer the question.

Table 3 summarizes the conceptual differences between IMSSA and conventional LCA. Given the tremendous uncertainty in data, methods, and model scope and structure, IMSSA emphasizes scenario analysis rather than simple point estimates (or ad-hoc confidence intervals). IMSSA results thus would be described with nuanced statements of this sort:

“Under the conditions A, B, and C, the distribution of climate-impact damages for policy option 1 tends to be lower than the distribution of damages for policy option 2. But option 1 also tends to result in lower vehicle miles of travel and lower GNP.”

Table 3. Summary of conventional LCA versus IMSSA

|                           | Conventional LCA Approach  | IMSSA  |
|---------------------------|--|--|
| Aim of analysis           | Evaluate impacts of replacing one limited set of linearly linked I-O processes with another                                  | Evaluate impacts (worldwide if necessary) of one realistic action compared with another                  |
| Scope of analysis         | Narrowly defined chain of energy and material production and use activities  | All energy, materials, economic, social, technological, ecological, and climate systems, globally        |
| Method of analysis        | Simplified, static, often linear energy-and-materials-in/emissions-out representation of technology                          | Dynamic, nonlinear, inter-related, feedback-modulated representations of all relevant systems            |
| What is evaluated         | Emissions aggregated by some relatively simple weighting factors (e.g., “Global Warming Potentials,” ozone-forming potential | Ideally, physical and economic impacts of direct interest to society (e.g., damages from climate change) |
| How results are expressed | Point estimates  | Distribution of results for a range of scenarios   |

Conclusion

As mentioned at the outset, this paper frames the discussion of IMSSA around the climate impact of biofuels because this is a particularly complex problem that nicely illustrates the deficiencies of conventional LCA. But might conventional LCA be acceptable for much less complex transportation-energy problems? In general, the more an energy alternative perturbs technological, economic, and environmental systems, the less suitable is conventional LCA. This suggests that, in principle, conventional LCA might be almost as accurate as IMSSA in estimating the impacts of alternatives that do not appreciably affect technological, economic, and environmental systems.

The problem, however, is that often it is difficult to identify low-perturbation alternatives without using relatively complex models to scope the potential impacts. This difficulty is compounded because generally, the harder analysts and scientists look, the more impacts they find. Even alternatives that at first glance seem to have very small impacts (e.g., wind, water, and solar power) can, upon further inspection, turn out to have potentially nontrivial impacts not covered by conventional LCA. For example, the deployment of wind turbines over the ocean may cause local surface cooling due to enhanced heat latent flux driven by an increase in turbulent mixing caused by the turbines (Wang and Prinn, 2011). Large-scale photovoltaic arrays in deserts can alter surface albedo. This affects local temperature and wind patterns, with the sign of the temperature effect depending on the efficiency of the photovoltaic system relative to the background albedo (very efficient PV systems will cause local cooling) (Millstein and Menon, 2011).

Nevertheless, resources for research are limited, and we cannot research everything forever. Ideally, we want to concentrate our efforts on problems that are important, uncertain, and tractable.<sup>4</sup> Given this, the most sensible approach is to evaluate periodically the state of our knowledge so that we can continue to target important, uncertain, and tractable problems. Unfortunately, at the beginning of this process, we need fairly comprehensive tools in order to do any kind of screening at all. Thus, we should develop at least rudimentary IMSSA as quickly as possible in order to guide the evolution of our analyses.

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<sup>1</sup> See DeLuchi (1991) for additional historical background and a review of early transportation LCAs.

<sup>2</sup> See the ISO web site, [www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html](http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html)

<sup>3</sup> Note that this general criticism applies to methods that use economic input-output (I-O) analysis, such as hybrid IO-LCA methods (e.g., Lenzen, 2002). IO-LCA expands the boundaries of the energy and materials systems considered, but does not necessarily address the other issues raised here.

<sup>4</sup> If a problem is unimportant, well understood, or intractable, it is not worth a great deal of attention. Thus, it is beside the point to argue that conventional LCA might be suitable for analyzing the impacts of policies that are intended to make only inconsequential changes in energy use, because there is no need to analyze such policies in the first place.

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### **Bio**

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# ***The Violinist's Thumb: Stories about Genetics, Retro Diagnosis, and Human Life***

**Presentation by Sam Kean  
at the  
Washington Academy of Sciences 2013 Awards Banquet**

**Editor's Note:** This is a transcription of the speech by Sam Kean at the Washington Academy of Sciences 2013 Awards Banquet. Kean is the author of the New York Times national bestseller, *The Disappearing Spoon*, and most recently *The Violinist's Thumb*. Both books were named among the top five science books of the year, and each was nominated for major awards here in the United States and abroad. The author and his books have been featured on NPR's "Radiolab," "All Things Considered," and "Fresh Air." References for these two Kean books appear at the end of this presentation.

## **Introduction**

*THE VIOLINIST'S THUMB* is a book about genetics on the surface, but really deep down, it's a story book. It's a book about stories of all aspects of human life. Sometimes they're very specific historical stories, about personal tragedies or triumphs, or people trying to prove or disprove an ancient legend. Some of the stories are bigger, more epic stories about who we human beings are and where we came from (e.g., Why did we almost go extinct at various points?) ... Big questions about our species.

One of the reasons I wrote the book is to show that — when it comes to genetics — genetics isn't just about medicine anymore. Genetics has spilled over into a lot of other areas of human life — like archeology, history, art, DNA computing, and using DNA to perform computations. I wanted to get all those stories together in one place.

## **Retro Diagnosis**

I thought I'd jump right in with probably my favorite example of using DNA in a new and different way, in a field I like to call "retro diagnosis." The point of retro diagnosis is to figure out how your favorite historical celebrity died. You look at when they lived, where they lived, their social circumstances, and what they complained about on their deathbed. From all these things, you try to piece together how they died; you retro diagnose them.

Doctors are really incorrigible about doing this type of work. If you flip through medical journals, you find paper after paper saying, “So-and-so died of this ... this artist must have had this disease ... everyone is an idiot for not realizing that emperor so-and-so died of this.” They really butt heads sometimes, because there’s not any historical evidence. Unfortunately, if you’re not careful, you can get unwarped from reality pretty quickly with some of these theories. A lot of times they rely on information compiled hundreds of years after people died. So it’s as much legend as it is fact. Or, a few hundred years ago, people just didn’t know as much about medicine, so they may have been inaccurate about what they were saying.

I’ve seen papers with serious suggestions, for instance, that Beethoven died of an STD [sexually transmitted disease]; he died of syphilis. Another paper said that Edgar Allen Poe died of rabies, which was kind of fitting with the lore at least. And another ... that Alexander the Great died of ebola, of all things. Just a partial list of all the things Charles Darwin supposedly suffered from in his lifetime includes: middle ear damage, pigeon allergies, arsenic poisoning, lactose intolerance, adrenal gland tumors, lupus, narcolepsy, agoraphobia, chronic fatigue syndrome, cyclical vomiting syndrome, and something called smoldering hepatitis.

I’ve even seen straight-faced suggestions trying to diagnose fictional characters with various ailments. Such as suggestions that Sherlock Holmes had autism ... that Ebenezer Scrooge had obsessive compulsive disorder ... that Darth Vader had borderline personality disorder (uh, borderline?).

Doing this type of work trying to retro diagnose people, you might think that DNA could be more objective. You just go in, test a little bit of bone or maybe some hair samples, and boom, you get an answer. They had a disease. Well, it may turn out they *didn’t* have a disease. As I explain in the book, it’s not always that simple. It actually takes a lot of interpretation to know what you’re doing and get a nice solid answer. So there are a lot of ambiguous cases out there still.

### **DNA, An Exciting New Lens to Look at History**

The story I’m going to talk about now is actually one of the big success stories doing this type of work with retro diagnosis. This story got started in about 1300 B.C. with one of the Egyptian pharaohs who was born Amenhotep IV. A few years into his reign, Amenhotep said, “Enough with the Amenhoteps. We’ve already had four of them. I’m going to

change my name to Akhenaten.” And that’s what he’s known as in history today -- the famous pharaoh Akhenaten.

Akhenaten was a reformer above all. He wanted to reform Egypt top to bottom. He started with Egyptian religious services. The people in Egypt traditionally worshipped at night and they worshipped a lot of different gods. But Akhenaten came in and said, “No, not anymore. I believe in one god. I believe in the sun god above. Because of that, we’re going to start worshipping during the afternoon, the sun god’s prime hours.” Unfortunately, he was a little rigid about this, and ended up making a lot of people very angry. For instance, he became something of a grammar Nazi. If people put the hieroglyphic for “gods” (plural) on a wall, he would have someone go in with a hammer and smash it because he didn’t want people even thinking about the idea that there could be more than one god. Or if a local family had a favorite god on a cup or plate or something like that, he would send his thugs into their house and they would take it and smash it on the ground because, again, he couldn’t stand the thought of people acknowledging another god. As you can imagine, this made a lot of people very angry.

But as heretical as Akhenaten was with religion, he was equally heretical when it came to art. During Akhenaten’s reign, you start to see a lot of realism -- very realistic birds, crocodiles, plants, and other pictures like that -- for the first time ever in Egyptian art. Even the people found themselves in very realistic scenes. Akhenaten might just be talking to his wife, the famous Queen Nefertiti. Or he might be sitting having breakfast with his son, the future King Tut. A lot of people were startled by this because they hadn’t imagined the pharaoh depicting himself in these normal, mundane, everyday ways.

For all the realism in Akhenaten’s reign, there was one thing that was decidedly unrealistic. That was Akhenaten, himself. Whenever you see pictures of Akhenaten, there is something a little “off” about him. He always looks a little strange. And if you listen to archeologists describe the various depictions they’ve seen, they can sound like carnival barkers. One promises, “You’ll recoil from this epitome of physical repulsiveness.” Another called him a “humanoid praying mantis.” If you listen to the symptoms they find, they go on and on ... an olive-shaped head, a concave chest, spidery arms, chicken legs with backwards-bending knees, botox lips, pot belly, just on and on ... the anti David or Venus de Milo of art history. Archeologists were always wondering, “What the heck happened here? He’s the pharaoh. He could have himself depicted however he wants

in any picture, and he chooses to look like this? Why would you do that to yourself?”

There was always one school of thought that said, “Well, maybe it was more realism. Maybe he did have a funny looking body. Maybe he had a genetic disorder of some sort.” And it wasn’t a bad guess because — to be frank — there was a lot of incest in the pharaohnic line. So it’s not implausible that he could have received a bum gene from one parent and the same bum gene from another parent and come down with a genetic disorder that would have left his body looking a little strange. But, of course, no one had any sort of hard evidence for this. They were just looking at pictures, squabbling back and forth with each other saying, “He had this ... no he didn’t ... yes he did ... no he didn’t.” Back and forth like this -- until genetics entered the scene.

It was really only when genetics entered the scene that they got a good handle on what was going on. In 2007, the Egyptian government finally let some archeologists and geneticists have samples from five generations of mummies including Tut’s and Akhenaten’s. They also did very meticulous CT scans on their bodies. From this work, they realized that none of the mummies had any sort of major deformities, no genetic disorders that they could tell.

From this they realized that the pictures -- which sure don’t look realistic -- probably weren’t even striving for realism. They were probably more like propaganda. The theory was that Akhenaten decided that his status as the pharaoh lifted him so far above the normal human rabble like you and me that he had to have a new body in public pictures to show that he was much different. Some of the depictions of him where he has a big pregnant belly were probably trying to tell people that he was the “womb” of Egypt’s well-being. Seems funny to show him as having a big belly, but it was effective propaganda.

Now, all that said, there were subtle deformities that showed up in the mummies. And with each generation that passed, they actually found more and more deformities like cleft palates or clubbed feet. Tut, of the fourth generation, actually had both a clubbed foot and a cleft palate. They realized why this was when they looked at Tut’s DNA.

All of us have inside us these very repetitive sections of DNA. It’s like someone held a finger down on the keyboard for a while. I call them DNA stutters — again, just repetitive sections. You get some of these stutters from your mother, some from your father. So they offer a good



way to trace lineages. Unfortunately for Tut, he got the same DNA stutters from both his mother and father. Because his mother and his father, in turn, had the same father. In other words, his mother and father were brother and sister. It turns out that Akhenaten's most famous wife may have been Queen Nefertiti, but when it came time to produce an heir for the throne, he actually turned to his sister, and the result was King Tut. Eventually, this incest compromised Tut's immune system and unfortunately it did the dynasty in. Akhenaten soon died and left the state in a mess, and the 9-year-old Tut had to assume the throne. The first thing he did was to try to renounce some of his father's heresies, hoping for a better fortune. But it didn't come.

They found out what happened to Tut when they looked a little closer at his DNA. In addition to his own DNA, they found scads of malarial DNA deep inside his bones. Malaria was pretty common back then. Both of Tut's grandparents (he only had two of them) came down with malaria at least twice, and they both lived with malaria into their 50's. So malaria wasn't necessarily a death sentence. But Tut, with his compromised immune system, came down with malaria at about 19 years old. If it didn't kill him, it weakened him so much that something else dispatched him pretty quickly.

In fact, we can tell how precipitously Tut died by looking even further into the DNA. There were always these strange brown splotches on the tomb inside Tut's wall. They were all over the tomb. Archeologists used to wonder, "What are these little splotches, and why are they here but nowhere else?" They realized what they were, but did some biological and chemical testing on them. They are actually molds; they are biological. What happened was, Tut died so quickly and unexpectedly, that they didn't have time to let the paint dry on the walls inside his tomb. They had to seal him up before they were ready. The paint was wet, so it attracted mold and ended up defacing a lot of the pictures in there.

So, powerful forces in Egypt never forgot the family sins. Tut died without an heir because he had turned to his sister to have children and neither of them could live because they were just too compromised. When Tut died without an heir, an army general seized the throne, and that army general died without a child. Then the famous General Ramses seized the thrown. Ramses had never liked the Akhenaten family, and he tried to erase them from the annals of the pharaohs. He decided he was just going to get rid of them. One of the things he really wanted to do was to get rid of Tut's tomb. So he ended up erecting buildings over it and pouring a

bunch of rubble over it to hide it from view, and he did a pretty good job of it. In fact, he did such a good job of hiding Tut's tomb that even looters struggled to find it over the generations. It all ended up backfiring on Ramses in that the treasures that survived intact made Tut the most famous pharaoh of all, even though he wasn't that important in his time. Really, the only reason we know about Tut today is because Ramses did this. He took over when he was young; he only lived 10 years, and didn't do a whole lot. But because his treasures survived intact, he's a very famous pharaoh today.

That story shows you can start with something pretty small and inconsequential like DNA and — if you're careful and know what you're doing — you can parlay that into a lot more information about the era's art, history, politics, and funeral practices. If you take a closer look at the DNA, all these different areas come to light. It shows how DNA is an exciting new lens to look at history ... something I was trying to do throughout the book.

### **DNA and Genes**

So, what is DNA and what are genes? They're related, of course, but they are distinct things. DNA is a chemical, a thing (you can get DNA stuck to your fingers!), and it has a specific job inside cells. Its job is to store and encode information. It works a lot like a language does.

Genes are a little more abstract, more conceptual. I like to think about genes kind of like stories, with DNA as the language that the stories are written in. So what kind of stories do DNA tell? Well, obviously, they tell stories about body traits. Why you have red hair ... why some people have blue eyes ... why some people have funny "hitchhiker thumbs" and things like that. They tell stories about your body. And of course if the DNA changes (if the DNA is damaged or mutated or something like that), the language changes and the meaning of the story changes.

What I find amazing about DNA is that DNA works the same basic way in all known forms of life. In all creatures, all plants that we can think of, DNA works in the exact same way — whether you're talking about tulips, guinea pigs, toads, toadstools, slime molds, members of Congress, whatever. DNA and genes work the same basic way in all of these weird creatures. I just find that fascinating.

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## Gene Names

But when it comes to DNA and genes, there's one thing that's not quite the equal between human beings and the rest of the animal kingdom. And that thing is the *names* of genes. If you look at the names of human genes, they're quite often long, really horrendous jargon-like words. They stretch on and on; random numbers pop up in the middle of them, and they're really hard to understand sometimes.

But scientists can have a little bit more fun with animal gene names. They can be a little bit looser and more creative. Specifically, I'm thinking about the gene names of the fruit fly. He might not look it, since he doesn't look particularly witty or funny, but the fruit fly has probably inspired more interesting, creative, unusual gene names than every other animal out there. There are fruit fly genes named "Groucho" ... "Smurf" ... "Lost in Space" ... "Fear of Intimacy" ... "Tribble" (after those little flying fuzzballs in that famous episode of Star Trek)... "Faint Sausage" (and I have no idea what the Faint Sausage gene does, but it's a wonderful name). There's the "Tin Man" gene, and if the Tin Man gene gets mutated, fruit flies cannot develop a heart. There's a gene that leaves fruit flies exceptionally tipsy after a tiny, tiny sip of alcohol. It's called the "Cheap Date" gene. And on and on ... there are so many great fruit fly gene names out there.

There's an occasional zinger out there with other animals, too. Probably my favorite gene name involves the "Pokerythroid Myeloid Ontogenic" gene. It's a perfect example of a terrible gene name, where you look at it and have no idea what they're talking about with these words. But if you look at the first three letters, there's a "p-o-k," then there's an "e," then the next letter at the beginning of the next word is an "m," and it kind of spells out "Pokémon." In fact, the scientists who discovered this gene in mice named it the Pokémon gene. They published a paper about it, and it became the official name of the gene. Everyone had a pretty good laugh about this, except you can see right behind the word Pokémon is a little "R" with a circle around it, and that means restraint. The lawyers at Pokémon Inc. were not amused by this because it turns out that the Pokémon gene contributes to the spread of cancer in mice, and they didn't want their cute little pocket monsters confused with tumors. They threatened to sue the heck out of these scientists and were really going to take them to the cleaners over this. So the scientists backed down and gave it another horrendous gene name. But, for one shining moment, there was actually a Pokémon gene.

## Human Beings and Intelligence

So far, I've been discussing mostly isolated genes, single genes. And that's how genetics got done for a very long time — people looking at individual genes. Scientists nowadays are really working with systems of genes — 5 genes, 10 genes, a dozen genes, even more, all at once, trying to figure out all the ways those different genes interact. This is really where the best science is going on. A lot of our very important traits are examples of lots of genes working together. The most obvious example is height. There's not one gene that makes you tall. It's hundreds of genes all working together, some adding a little, some subtracting a little, all coming together to give you the height that you have.

Another great example, although one that's much more controversial, is *human intelligence*. What is, if anything, the genetic basis of human intelligence? How much can we trace to that?

There have always been two schools of thought about this issue of human beings and intelligence. There's one school of thought that says the most interesting thing is, "Why are human beings, in general, so much smarter than our relatives like chimpanzees and gorillas. What is it that makes the general human person so much smarter?"

Then there is another group of scientists who say, "That's an okay question, but what I'm really interested in is what sets some human beings apart from other human beings? What makes geniuses? Why are some people so smart?" This second group of scientists has always said, "If we want to learn about what makes human geniuses, we've got to study the brains of the smartest people out there. People like Albert Einstein."

## Einstein's Brain and Other Stories

As some of you may know, we actually do have Einstein's brain preserved in a jar to this day. Unfortunately, it's kind of a gruesome story. It got started in April 1955. Einstein had an aortic aneurysm, a little tear in his aorta which is pretty fatal. He lingered on for a few days and died at about 1:15 in the morning at a hospital in Princeton, New Jersey. They called in a local doctor named Thomas Harvey to do the autopsy, and it should have been a pretty straightforward one, opening him up to make sure it was an aortic aneurysm, and then giving the body back.

But Thomas Harvey was kind of ambitious. He got to thinking and said, "This is the grey matter of the greatest scientific thinker since Isaac Newton. We have one chance to save his brain. It's not like we can go

back a month from now and get his brain then. It has to be tonight, or never.” I think a lot of us might have felt the same temptation that Thomas Harvey did, but I’m not sure we all would have done what Thomas Harvey did which was to saw open Einstein’s head, remove the brain, sew the body back up, and give it back to the family without telling them that he was did this.

Unfortunately for him, Thomas Harvey was a little excitable and he liked to talk. He got home that morning and told his wife about this, and also told his young son. The next day at school, the teacher was talking about Einstein, and what a loss his death was to the community, and the kid’s hand goes in the air (who can blame him) and he said, “My dad’s got Einstein’s brain.” Some newspapers got hold of the story and, as you can imagine, Einstein’s family was not very amused to find out this way what happened to his brain.

Unfortunately, this is not the first celebrity autopsy to take a lurid turn like this. When Beethoven died, doctors set aside some of his inner ear bones because they wanted to study his deafness. Well, an orderly walked by and put them in his pocket, and no one ever saw them again. Haydn, the famous composer ... [when he died], phrenologists stole his head because they wanted to see what made a composer, and no one really knows to this day where it is. Thomas Edison, on his death bed ... someone put a jar in front of his face to capture his last breath, and then quickly put a lid on the jar. The jar actually ended up in a museum, and people came from miles and miles to see this jar with some air inside it. But it was considered very impressive at the time.

Probably the worst of these stories involves Albert Einstein again. Because as soon as Thomas Harvey got done with him, another New Jersey doctor came in and plucked out his eyeballs and put them in a security deposit box in a bank, and they sat there for years and years. At some point in the 1980s, who else but Michael Jackson offered \$3 million dollars to get his hands on Einstein’s eyeballs. But the doctor who took them said, “No, they weren’t for sale, in part because he’d grown fond of taking them out and gazing into them every now and then.”

I don’t lump Thomas Harvey in with these sorts of creeps and weirdos. He at least had a serious scientific purpose: To study Einstein’s brain and see what made him so smart. The first thing he did was take Einstein’s brain and weigh it. The disappointment started almost immediately because the average human brain weighs around 50 ounces, and Einstein’s brain weighed 43 ounces. It was on the low end of normal,

and one of the smallest brains Thomas Harvey had ever seen. We call people who are very smart “big brains,” but that was not at all the case with Albert Einstein.

The next thing he did was chop up the brain into little pieces. He shellacked them with a hard plastic coating, put them in mayo jars his wife had cleaned out, screwed on the lids, and mailed them to neurologists around the country so they could look at them under the microscope. He said, “I want to know what made Einstein so smart. What was unusual about his brain?”

The first round of neurologists got back to him and said, “We didn’t see a whole lot. Nothing really jumped out at us.” So Thomas Harvey said, “Well, they didn’t know what they were talking about.” So he got all the mayo jars back and sent them out to another set of neurologists and asked, “What made Einstein ‘Einstein’? And they said, “Funny thing. We agree with the first group, and didn’t find much that was unusual. It looked like a normal old man’s brain.” The more Thomas Harvey sent it out, the more he got the answer that it just looked like a pretty normal brain.

There have been more studies over the years. There was one not too long ago saying they might have found a slightly unusual fold in his brain or a slightly higher density of neurons, but for the most part neuroscientists don’t quite trust these judgments because they’re working with a sample size of one. There is just one Einstein brain so they really don’t necessarily know what made it special. Maybe it was just an unusual feature of Einstein’s brain. One objection, for instance, is that there are certain brain parts that look bigger in Einstein’s brain. Well, it turns out you also sort-of buff up those parts of the brain when you play music for a long time. Einstein played the violin from the time he was 6 or 7 years old, and he kept playing his whole life. So, did music help him or was it his amazing spatial skills? No one really knows. Over the years, Thomas Harvey got the samples back and eventually just put them in two wide-mouthed cookie jars inside a cardboard box, and put this in his office behind a beer cooler, and that is where Einstein’s brain sat for decade after decade.

### **The Genetic Basis for General Human Intelligence**

Meanwhile, that other group of scientists — the group that is interested in figuring out why are human beings so much smarter than chimpanzees and other apes — was actually making a fair amount of

headway in figuring out the DNA and the genetic basis for some of our general human intelligence. Some of the findings are a little preliminary so we have to be a little cautious, but they are starting to give us the first real insight into what made human beings so smart.

The DNA related to our intelligence has been analyzed in various roundabout ways. One example has to do with our jaw muscles. If you've ever seen a gorilla jaw, they are very big, thick jaws. It turns out that we had a mutation a while ago that deactivated one of the genes that closed up our jaw muscles. So we have much thinner jaws. Because we have thinner jaws, this leaves a little more room in the skull — a few cubic centimeters for the brain to expand into. So, our brain was able to get a little bit bigger because we have a thinner jaw.

Another surprise was a gene called APOE, which is a gene that was originally linked to allowing human beings to be able to eat more red meat because it manages cholesterol. Well, it turns out that the brain needs cholesterol, too. Brain cells called neurons have these long axons on them that help send information out. These axons have a sheath on them called myelin, and one of the major components of myelin turns out to be cholesterol. Some versions of the APOE gene do a better job bringing cholesterol where it's needed, so it is linked in some general way to human intelligence — and also to brain plasticity, another important part of intelligence.

Some genes lead to direct structural changes in the brain. There's a gene called the LRRTM1 gene (another terrible gene name). It helps determine exactly which patches of neurons control memory, speech, and other things like that. Brains actually vary as much as faces do; the patches shift around inside your head. Some versions of the LRRTM1 gene can even reverse parts of the left and right brain. It also increases your chances of being left handed, which is one of the only known associations for that trait.

I find this really fascinating: Scientists have found 3,100 base pairs of so-called junk DNA or non-coding DNA in chimpanzees that got deleted in human beings. This area of non-coding DNA helps stop out-of-control brain cell growth. Out-of-control brain cell growth may sound great because you can get a really big brain that way. Unfortunately, it also leads to tumors. So human beings really gambled in deleting this stretch of DNA, but it turns out the gamble paid off, and our brains ballooned as a result. I think that story shows it's not always what we *gain* with DNA, but rather sometimes what we *lose* that helps make us human.

The point is that it's not just one gene or one mutation that suddenly made human beings very smart. It was a suite of genes. A lot of different things worked together in very small bits and added up to giving us the general intelligence that we have.

### **What Makes a Genius?**

But there are always those other scientists out there addressing what is still a really intriguing question. What does make genius? What makes some human beings smarter than others? What separates them from the rest of us? You might be thinking, "We know something about the DNA as to what made human beings, in general, smart. We also have Einstein's brain. Maybe we can look at Einstein's DNA to figure out what made him so smart."

Unfortunately, it didn't quite work out, and I'm going to finish up the Einstein story by explaining why. Thomas Harvey eventually lost his job in New Jersey and, tiring of life there, he took off for greener pastures in Kansas. In Kansas, he actually moved in next door to the author William Burroughs, so they were neighbors in Kansas. Einstein's brain rode shotgun in Thomas Harvey's car when he was going across the country, and Einstein's brain got back on the road in 1998 when Harvey and the writer Burroughs got in a rented Buick and drove cross-country to California to visit Einstein's granddaughter, Evelyn.

Evelyn was a little weirded out when they showed up with grandpa's brain, but she allowed them to come in for one reason: she was poor and didn't have much money. She had a lot of trouble holding down a job. She reputedly wasn't very smart, and so was not exactly an Einstein. In fact, she'd always been told that she had been adopted by Einstein's son, Hans. But Evelyn had heard rumors that after Einstein's wife died he actually ran around with a lot of different lady friends in the Princeton area. And she realized that she might actually be Einstein's illegitimate child, and the adoption might have been a ruse. She wanted to get a paternity test to settle things once and for all, but unfortunately the embalming process Harvey used ended up denaturing the DNA inside the brain, so it ended up being useless. There might be other sources of Einstein's DNA out there ... hairy mustache brushes, spittle on pipes, or sweat on violins. There are all these possibilities, but for now, we actually know more about the genes of Neanderthals who died 50,000 years ago than about the genes of a man who died in 1955.



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## Surviving Hiroshima and Nagasaki

One of my favorite stories in the book involves a man who was visiting Hiroshima in August of 1945 when he saw a plane flying overhead and a little tiny speck fell out of it at about 8:00 in the morning, the atomic bomb. He saw it go off, and was thrown back and burned all over his body. Hiroshima was devastated but he decided, “I have to get out of here. I have to get back to my home town.” So he struggled for a few days and got to the train station and finally got going on a train. The next day he pulled into his home town which was Nagasaki, right in time for the next atomic bomb to go off! So he was probably one of the most unlucky men of the 20th century. But the kicker on this story is that he actually lived until 2010; he lived 65 extra years after the atomic bombs went off. In the book I talk a little about how it was possible that his DNA survived that and what probably set him apart from other similar people — because he should have gotten cancer. It has to do with DNA repair mechanisms.

## Summary: The Overarching Story

As I say, there are a lot of other stories in the book, but the overarching theme is the bigger story about who we human beings are. Besides what we normally think are the benefits of genetics — things for our physical bodies like instant diagnoses or medical panaceas — I think one of the real impacts of genetics is going to be a sort of mental enrichment, even a kind of spiritual enrichment ... a deeper sense of who we human beings are ... where we came from ... how we fit in with other life on Earth ... all of these different things.

Right now is really a special time with regard to these stories. A lot of them happened thousands upon thousands of years ago. They can serve as cornerstones or turning points into a history that we thought we’d never be able to learn about because they happened so long ago. But it turns out that our cells have been copying these stories inside us for millions (and sometimes for billions) of years. And it’s only in the past decade or decade and a half that we’ve really been able to read these stories for the first time. So I hope this talk tonight and I especially hope *The Violinist’s Thumb* has been able to capture that excitement of being able to read these stories for the very first time.

**Question: What is the significance of the title  
of the book, *The Violinist's Thumb*?**

It's one of the stories from the book about the violinist Niccolò Paganini, usually considered the greatest violinist who ever lived. He was active in Europe around the 1800s. He played for kings, popes, and Napoleon, and all these types of people. There were rumors he sold his soul to Satan for his talent — that's how good he was! But one of the real reasons he was good was that he had these amazing, freakishly flexible hands. For instance, he could bend his pinky then make a right angle with the rest of his hand. He could also put his hand down flat on a table and touch his thumb and pinky behind. He could do things with his hands that you should not be able to do with your hands. That was one of the reasons he was such an amazing violinist because he could move his hands all over the place ... stretch them incredibly wide ... do things that lesser violinists couldn't.

From a modern perspective, it's almost certain he had a genetic disorder of some sort because he could do this with all of his joints. All of his joints were bending the wrong way all of the time.

I chose this as the title story for a couple of reasons. One, it shows you can use DNA to get at something like music history where there didn't seem to be much of a connection, but you can ultimately get some interesting insight.

The other reason was it highlighted an important theme of the book. Paganini had these amazing hands, but he was also a very hard worker and loved playing music. So it was really his genetic endowments, his temperament, and his environment all coming together — a “perfect storm” of traits that made him who he was. It wasn't just his genes; it was his genes, environment, and temperament all working together. That's the meaning of *The Violinist's Thumb*.

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**Washington Academy of Sciences Annual Awards  
Banquet\***

**October 10, 2013, Arlington, Virginia**



Washington Academy of Sciences Annual Awards Banquet, Fall 2013



Washington Academy of Sciences' 2013 Annual Awards Banquet at the National Rural Electric Cooperative Association conference center

*\*Photos by Duy Tran Photography*



Master of ceremonies **Terrell Erickson**, President-Elect of the Washington Academy of Sciences, and banquet speaker **Sam Kean**



Keynote speaker **Sam Kean** engaging the group



Author **Sam Kean** presenting stories from his book, *The Violinist's Thumb*



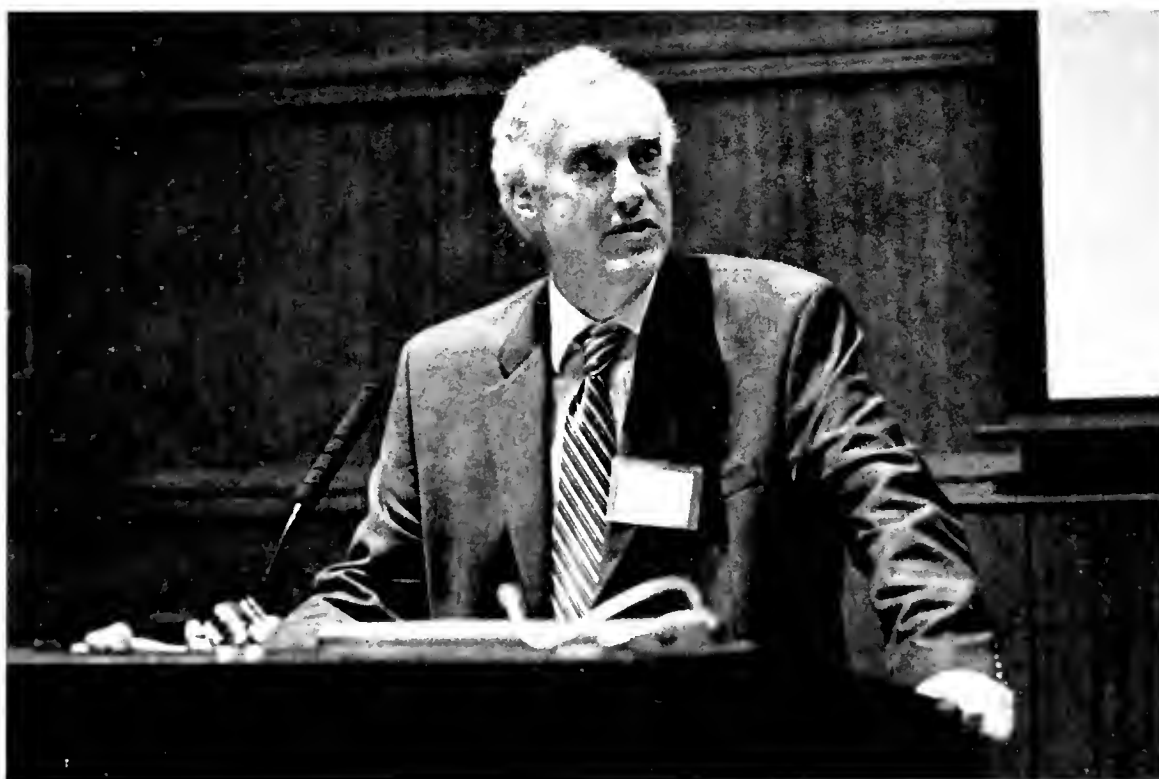
Washington Academy of Sciences Past President **Al Teich** (left) and Science Policy award recipient **David Goldston**



Washington Academy of Sciences Awards Committee Chair **Sethanne Howard** presenting the Distinguished Career in Science award to astronomer **Nancy Roman**, NASA retired (In Absentia)



Attendees enjoying the Awards Ceremony speakers



**David Goldston**, Director of Government Affairs for the Natural Resources Defense Council, accepting the award for Science Policy





**Al Teich**, Research Professor of Science, Technology and International Affairs at the George Washington University, presenting the award for Science Policy



Washington Academy of Sciences President-Elect **Terrell Erickson** presenting the Environmental Sciences award to recipient **Dennis Thompson** (not photographed), National Range and Grazing Lands Ecologist with the U.S. Department of Agriculture





Wakefield High School (Arlington, Virginia) Assistant Principal **Betty Sanders** (left), who presented the Lamberton Award; award recipient **Verlese Gaither**, and Washington Academy of Sciences President **Jim Egenrieder**



**Verlese Gaither** accepting the Lamberton Award for Elementary and Secondary Education



**Stuart Antman**, Distinguished University Professor at the University of Maryland's Institute for Physical Science and Technology, presenting the award for Mathematics and Computer Sciences



Mathematics and Computer Sciences award recipient **Pete Stewart** (left), Distinguished University Professor Emeritus at the Institute of Advanced Computer Studies, University of Maryland; and **Stuart Antman**



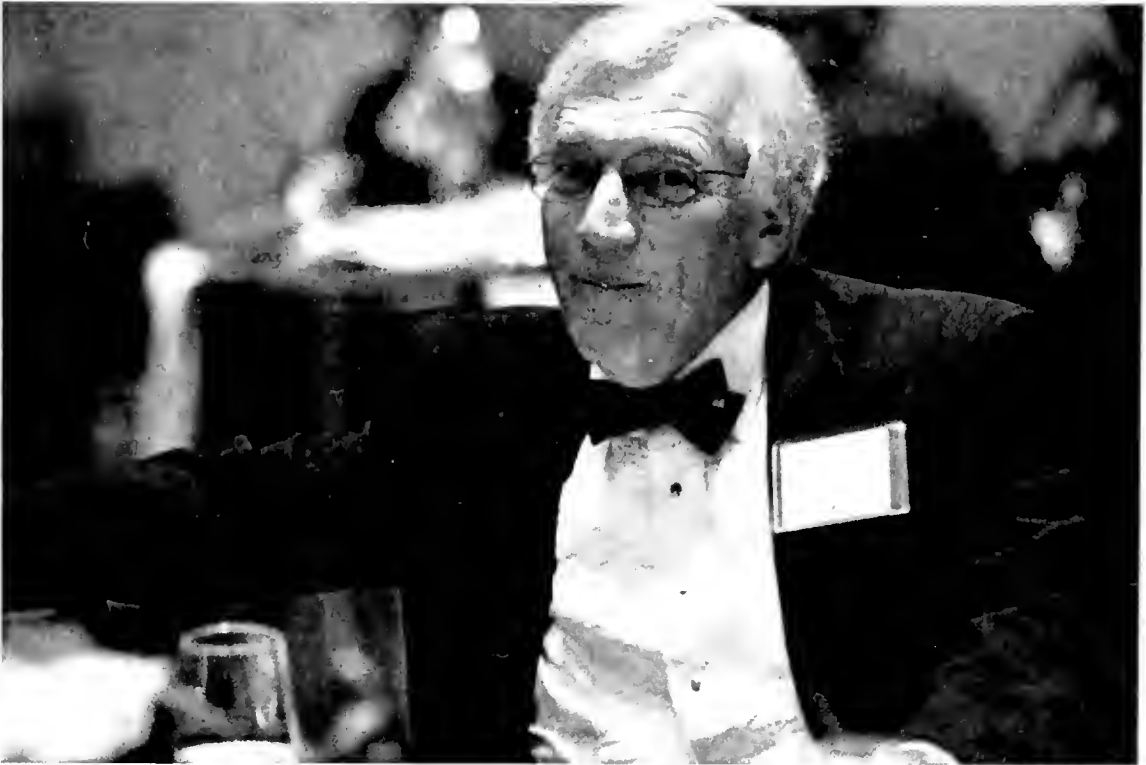
**Martin Apple** (far left), Past President of the Council of Scientific Society Presidents; Health Sciences award recipient **Douglas Wear**, Pathologist with the Armed Forces Institute of Pathology; and Health Sciences award nominator **Mina Izadjoo**, Senior Distinguished Scientist and Director of the Diagnostics and Translational Research Center of the Henry Jackson Foundation



Washington Academy of Sciences Vice President for Affiliated Societies **Richard Hill**



Katharine Gebbie (left) and Mathematics and Computer Sciences award recipient **Mary Theofanos**. Computer Scientist at the Information Technology Laboratory, National Institute for Standards and Technology



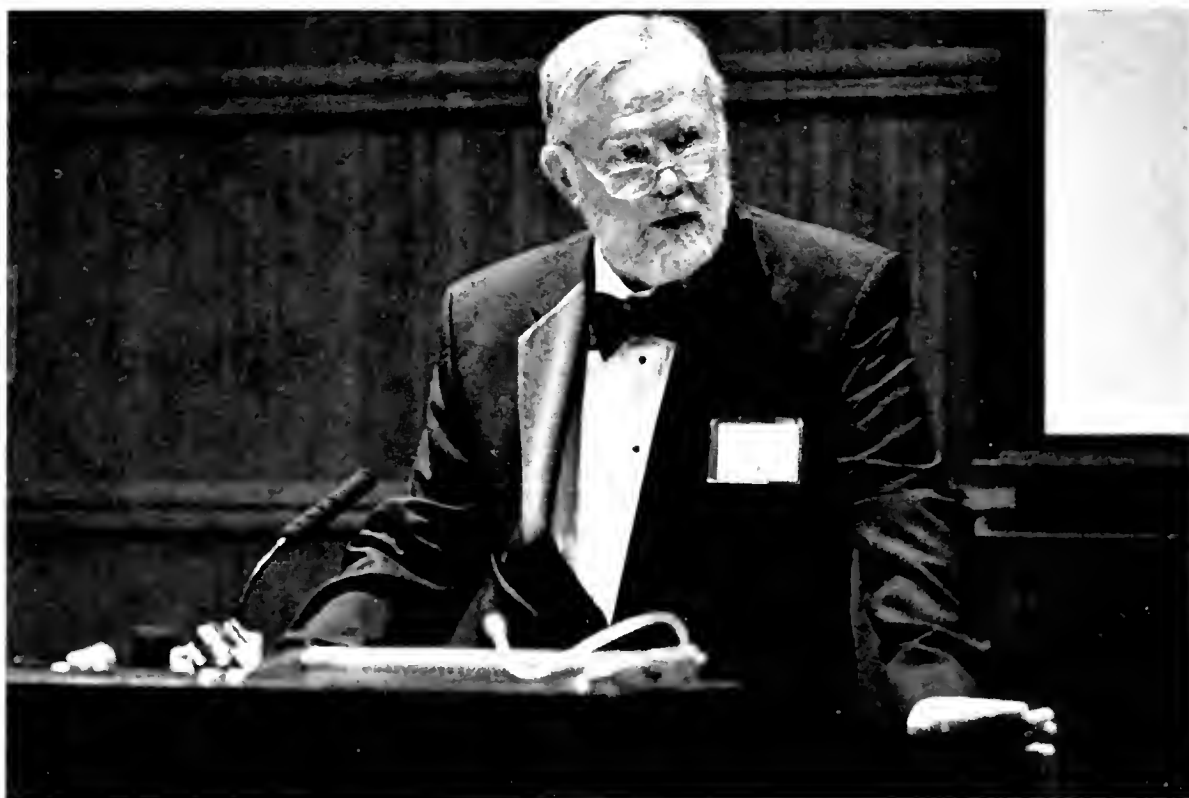
Washington Academy of Sciences Past President **James Cole** of the U.S. Naval Research Laboratory



**Katharine Gebbie**, a long-time director of the Physics Laboratory at the National Institute for Standards and Technology (retired), presenting one of the awards for Mathematics and Computer Sciences



Nominator **Bhatka Rath**, Associate Director of Research at the Naval Research Laboratory, presenting award for Chemistry



**Carter White**, Senior Scientist at the Naval Research Laboratory, accepting the award for Chemistry





Washington Academy of Sciences Vice President for Affiliated Societies, **Richard Hill** (left) and the Academy's Secretary, **Jeff Plescia**



Washington Academy of Sciences 2013 Awards Banquet attendees listening to keynoter **Sean Kean**

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## Washington Academy of Sciences 2013 Awards Program

| <b>Awardee</b>    | <b><i>Award</i> (and presenter)</b>   |
|-------------------|---|
| Nancy Grace Roman | <i>Distinguished Career in Science and Technology</i><br>(presented by Sethanne Howard)       |
| Carter White      | <i>Chemistry</i><br>(presented by Bhatka Rath)  |
| Mary Theofanos    | <i>Mathematics and Computer Sciences</i><br>(presented by Katharine Gebbie)                   |
| Pete Stewart      | <i>Mathematics and Computer Sciences</i><br>(presented by Stuart Antman)                      |
| David Goldston    | <i>Science Policy</i><br>(presented by Al Teich)  |
| Verlese Gaither   | <i>Lamberton Award for Elementary and Secondary Education</i><br>(presented by Betty Sanders) |
| Dennis Thompson   | <i>Environmental Sciences</i><br>(presented by Terrell Erickson)                              |
| Douglas Wear      | <i>Health Sciences</i><br>(presented by Mina Izadjoo)   |



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## In Memoriam

Clifford Lanham

(January 24, 1938 - September 18, 2013)

Clifford E. Lanham, a long time member of the Washington Academy of Sciences and its delegate representing the Washington Area Chapter of the Technology Transfer Society (T2SDC), passed away on September 18, 2013.



Cliff was a well-known and much respected participant in the Washington area technology transfer scene. He was a founding member of the Washington Area Chapter of the Technology Transfer Society and was a leader in creating meaningful programs. He was an active member of the T2SDC Board of Directors and managed the Technology Transfer and Innovation Forum presentations for the past several years.

In the 1990s, Cliff established the U.S. Army Research Laboratory (ARL) technology transfer program and functioned as its first manager. He was active in the formation of the Federal Laboratory Consortium for Technology Transfer and served as the ARL representative. Upon retiring from the Federal establishment, Cliff served as a volunteer with the Rockville Economic Development Corporation where he played a lead role in establishing the highly-successful annual Post Doctoral career event.

Cliff was passionate in his belief in the difference that technology transfer can make in society. His drive and enthusiasm for technology transfer was felt by many and he will be missed.

Anyone wishing to communicate with Cliff's son, Alex Lanham, and Alex's son Storm, may contact them at [CliffLanhamMemorial@gmail.com](mailto:CliffLanhamMemorial@gmail.com). Memorial donations may be made to the American Association for the Advancement of Science (AAAS).





# Washington Academy of Sciences

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## Journal of the Washington Academy of Sciences

**Editor** Sally A. Rood, PhD [sally.rood2@gmail.com](mailto:sally.rood2@gmail.com)

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## Editor's Comments

**Armando Pena** and **Elizabeth Schott** of the West Point Military Academy have written an outstanding “Washington, DC-oriented” version of their paper that won the student paper competition at the 2nd annual Industrial and Systems Engineering World Conference. The paper is “Modeling El Paso-Juarez Illicit Drug Networks: Policy Implications,” and the conference was sponsored by the Society for Industrial and Systems Engineering, November 5-7, 2013, in Las Vegas. We congratulate the conference co-chairs who included Washington Academy of Sciences members **Dr. Jeffrey Fernandez** and **Dr. Anand Subramanian**.

Also featured in this issue is the December 16, 2013 keynote speech by **Deborah Wince-Smith**, President and CEO of the Council on Competitiveness, for the 40<sup>th</sup> Anniversary Distinguished Speaker Series of the Science and Technology Policy Fellowships Program at the American Association for the Advancement of Science (AAAS). Throughout 2013 the series featured noted scholars, scientists, and policy leaders sharing their insights and discussing today's most compelling science policy issues — issues with implications from national to global perspectives. This keynote speech was the concluding address for the series and is entitled, “Future Directions for the U.S. Research and Innovation Enterprise”

It is the custom for this Journal's winter issue to include an annual directory of members of the Washington Academy of Sciences. This provides the opportunity to urge any readers who are not members to join, and for members to urge the libraries that they use to subscribe to the Journal. To find out how to do either, please contact Journal editor Sally Rood at [sally.rood2@gmail.com](mailto:sally.rood2@gmail.com) or see the Academy's website, [www.washacadsci.org](http://www.washacadsci.org).

I'm sad to say that in this issue we are also reporting on the passing of a two long-time Academy members: Lifetime Fellow **Dr. Abolghassem Ghaffari** and former WAS President, **Dr. John H. Proctor**.

Sally A. Rood, PhD, Editor  
*Journal of the Washington Academy of Sciences*  
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# Modeling El Paso-Juarez Illicit Drug Networks: Policy Implications<sup>\*</sup>

**Armando Pena and Elizabeth Schott**

United States Military Academy, West Point, New York

## Abstract

In the past decade, El Paso, Texas, has been considered one of the safest cities in the United States with a population over 500,000 people. Just across its border though, sits Ciudad Juarez, considered one of the most dangerous cities in the world. There is a unique social ecosystem between the two cities, a product of many years of shared history and traditions. The El Paso-Juarez area also happens to be one of the most valuable plazas for the Mexican Drug Cartels. Now that the territory is dominated by one cartel, the Sinaloa Cartel, drug trafficking through the area will likely increase and smuggling through border crossing check points will continue to be prevalent. The purpose of this research effort is to assist the Border Patrol in allocating its resources towards improved interdiction of illicit trafficking. Whether it is manpower, money, technology, or any other resource, the Border Patrol desires to efficiently allocate to maximize interdiction. This analysis is intended to suggest a tool that will assist in allocating resources and aid the extremely important effort to maintain El Paso, Texas, as the safest city in the U.S. by keeping drugs away from the streets. This research presents a network flow model of the complex illicit trafficking network operating in the El Paso-Juarez area, and provides insight that will aid agencies such as the Border Patrol in allocating its resources.

## Modeling El Paso-Juarez Illicit Drug Networks

“EL PASO WELCOMES YOU to the safest city in America,” a recorded voice tells travelers arriving at the city’s airport. With a rate of 1.9 homicides per 100,000 residents in 2010, the city of Texas’ western extremity ranked number one that year, and again in 2011 (Washington Office on Latin America, 2011) and in 2013, as the safest of all U.S. cities with a population over 500,000, according to a study by Congressional Quarterly Press. Whether measured in the \$18 billion spent annually on border security, the 22,000 National Guard soldiers, the record number of

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<sup>\*</sup>This paper was the winner of the student paper competition at the 2nd annual “Industrial and Systems Engineering World Conference,” November 5-7, 2013, in Las Vegas, Nevada, co-chaired by **Dr. Jeffrey Fernandez**, **Dr. Anand Subramanian**, and others. See <http://www.ieworldconference.org> for more information on the conference, sponsored by the Society for Industrial and Systems Engineering (SISE).

criminal deportations in the past four years, or the record-low immigrant apprehensions this past year, the fact is that the border has never been safer (Manning, 2013). However, Mexican cartels are in a state of war to control such crossings as this, and the fact is that drugs are flowing constantly through Juarez into El Paso and into the rest of the United States.

On the other side of the border, the battle in Juarez, Mexico, over the control of drug trafficking into El Paso began in 2008. The Juarez Cartel, Beltran-Leyva Organization, and remnants of the Gulf Cartel (including Los Zetas) have been battling against the Joaquin Guzman-Loera (El Chapo), Ismael Zambada-Garcia, Juan Jose Esparragosa-Moreno, and Ignacio Coronel-Villarreal Organizations for control of drug trafficking in the Plaza (High Intensity Drug Trafficking Area Program, 2009). Since then, conflict has spread across much of Mexico's north, as various cartels, street gangs, local police, and Mexican Army units battle for legitimate authority. The 2010 homicide rate was well over 200 per 100,000 residents. More than 9,000 people have been murdered in Juarez since 2009 (Washington Office on Latin America, 2011). As a former Juarez resident, before 2008, I [Pena] was able to go out with my friends at night, play at any park, walk anywhere, and visit other people in neighborhoods that we did not know. After 2008, the night life disappeared. Shootings at restaurants, bars, parks, hospitals, schools, and any other place you can imagine made our houses the only safe place.

While the recent war among various gangs and drug cartels in Mexico has made Juarez, Mexico, one of the world's most dangerous cities, El Paso, Texas, remains calm, even eerily prosperous. Still, some three million people are linked at this border, by ties of blood and commerce, and its fluid social ecosystem still retains something unique and emblematic and perhaps, worth saving. The fluid social ecosystem is based in tradition, family, and uniqueness. Most people living in Juarez have family and close friends on the other side of the border. The close relationship between the two border towns is deteriorating due to the violence as the drug cartels battle to control illicit drug trafficking through the area.

The purpose of this effort is to conduct a detailed modeling investigation into the illicit drug trafficking network in the El Paso-Juarez border area based on a holistic system analysis. Our goal is to develop a viable model that can be used by the Border Patrol in the area of El Paso, Texas, to better allocate their resources, so people like me [Pena] and



other El Paso residents are able to feel more secure and assured that the drugs flowing in Juarez, Mexico, stay away from our streets, and more importantly, from our people. Through extensive research, analysis, and system engineering problem solving, we propose a simplified network flow model that estimates drug flow by mode of transport through ports of entry (POE) in El Paso. These results can provide insights to allocating Border Patrol resources.

### ***Federal Strategy Against Drugs***

Illicit drug use in America contributed to an estimated \$193 billion in crime, health, and loss of productivity costs in 2007, the year for which the most recent estimate is available. The 2012 National Drug Control Strategy serves as the nation's blueprint for reducing drug use and its consequences. Since 2009, the Federal Government has spent more than \$31 billion on drug control, including \$9.4 billion in fiscal year 2012 for U.S. Law Enforcement and Incarceration and \$3.6 billion for Interdiction (Office of National Drug Control Policy, 2012).

### ***The West Texas High Intensity Drug Trafficking Area***

The West Texas High Intensity Drug Trafficking Area (HIDTA) encompasses El Paso and overall includes 10 counties in West Texas that lie along a 520-mile section of the U.S.–Mexico border. El Paso POE are extensively used by traffickers to smuggle drug shipments into the HIDTA region. Traffickers use private and commercial vehicles and couriers on foot to transport drug shipments into the U.S. The following are some examples of seizures that demonstrate the methods that traffickers use to conceal and transport illicit drugs into the HIDTA: 120 kg of marijuana concealed in the fuel tanks of a tractor-trailer at the Zaragoza POE seized in December 2008; 2.7 kg of marijuana packaged in bundles and taped to the legs and midsection of a pedestrian seized at the El Paso del Norte POE in October 2008. These examples are utilized to model illicit trafficking methods of transportation and their capacities (High Intensity Drug Trafficking Area Program, 2009).

### ***Border Patrol***

Customs and Border Protection (CBP) is one of the Department of Homeland Security's largest and most complex components, with a priority of keeping terrorists and their weapons out of the U.S. It also has a responsibility for securing the border and facilitating lawful international

trade and travel while enforcing hundreds of U.S. laws and regulations, including immigration and drug laws (CBP, 2013).

Today, the El Paso Sector is one of nine Border Patrol Sectors that run along the Southwest Border of the U.S. with Mexico. The sector is comprised of eleven stations and covers the geographical region of the entire state of New Mexico and two counties within far west Texas. The El Paso Sector employs approximately 2,400 Border Patrol agents, six permanent vehicle checkpoints and patrols 268 miles of international border encompassing 125,500 square miles (CBP, 2013).

El Paso Sector is understaffed according to interviews by the Washington Office on Latin America (WOLA). In 1993, there were 3,444 Border Patrol agents stationed along the entire U.S.-Mexico border, 608 of them in the El Paso Sector. By 2011 there were 18,506 Border Patrol agents along the border, 2,738 of them in the El Paso Sector. Although El Paso has seen growth in numbers, this growth has been by proportion lower than growth in other sectors contributing to El Paso, ranking only seventh in apprehensions (Washington Office on Latin America, 2011). Efficient allocation of personnel can improve interdiction efforts. The scope of this project initially focuses only on the El Paso-Juarez border within the El Paso Sector.

### *Ports of Entry*

The El Paso-Juarez region's international border crossings are a system of regional, statewide, and national significance. They facilitate billions of dollars of trade, providing access to schools and businesses, and contributing to a shared regional culture and lifestyle. Most drugs pass right under border guards' noses, smuggled in some of the tens of thousands of cars and trucks that pass daily through these official ports of entry (POE).

Historical data captures the volume of trucks, buses, privately-owned vehicles (POV), and pedestrians moving through the POE from Juarez to El Paso by bridge and by month for 2011 (U.S. Customs Service and Border Protection, 2012). This data will be used to estimate the capacity of each POE that will be used in our model. For example, in January at the Paso Del Norte POE, there were 197,558 POVs and 342,956 pedestrians crossing. Additionally, drug seizure data is also available in order to estimate the amount of drugs transported across the border. Border Patrol seized 27,482 kg of illegal drugs at the El Paso area POE in fiscal year 2010. Although seizure amounts are broken down into

various drug types (marijuana, cocaine, heroin, and methamphetamine), we will model drugs as a whole, estimating the annual combined supply of drugs the Sinaloa Cartel is attempting to ship (High Intensity Drug Trafficking Area Program, 2009).

### ***Methods of Crossing Illegal Drugs***

Most drugs cross into the U.S. through the main POE in trucks and POVs. Pedestrians also cross drugs by hiding them in their boots, jackets, pockets, or other creative ways. Ultra-light aircraft and tunnels are also used.

Mexican organized crime groups use ultra-light aircraft to drop marijuana bundles in fields and desert scrub across the U.S. border. The incursions are hard to detect and are on the upswing. The pilots release 250 pound (110 kg) payloads that land on the American territory (Marosi, 2011). We will use the capacity of the ultra-light aircrafts in our model.

Drug-smuggling tunnels are very rare in El Paso. However, in June 2010, Border Patrol discovered a tunnel used by traffickers stretching 130 feet under the concrete-lined Rio Grande. Though small, dark and unventilated, the tunnel allowed people to crawl from Mexico to the U.S. The Border Patrol found 90 kg of marijuana inside the tunnel and arrested a 17-year-old from Mexico (Hinojosa, 2010). Consequently, our model will use five methods of transportation to include trucks, POV, and pedestrians through the main POE, and ultra-light aircraft and tunnels through the wilderness area in the Anapra vicinity.

### ***Measuring Border Patrol Effectiveness and Allocating Resources***

The 2012-2016 Border Patrol Strategic Plan establishes the approach that the Border Patrol uses in designing operations to meet their diverse challenges in policing the U.S. border. This Border Patrol's plan "builds on the foundation of the 2004 National Border Patrol Strategy, which guided the acquisition and deployment of significant additional resources — personnel, technology, and infrastructure — to support execution of the Border Patrol's mission" (CBP, 2013). The current Strategic Plan implements operations on a risk-based approach, focused on "identifying high risk areas and flows and targeting our response to meet those threats" (CBP, 2013). In essence, the Border Patrol deploys resources to meet the highest priority threats. However, how the Border Patrol actually defines the highest priority threats and allocates resources to target those threats remains somewhat elusive.

The Strategic Plan incorporates two goals in support and each goal has five sub-objectives. Their first goal is to Secure America's Borders and their second goal is to Strengthen the Border Patrol. Within this structure, the Border patrol has developed an initial framework with the intent to measure operational and tactical effectiveness. However, they have not yet developed good performance measures to use within this framework to analyze the effectiveness of their operations and truly understand how well they are achieving their results given their resources. Stated within the Strategic Plan, the Border Patrol is continuing to develop and continually to refine "comprehensive, demanding, and results-driven performance measures that hold us to account. Even as the organization internalizes these standards, it also must effectively communicate overall performance to its most important stakeholders — the American public" (CBP, 2013). The Strategic Plan itself suggests the Border Patrol can improve how they currently allocate their resources.

Additionally, in December of 2012, the U.S. General Accountability Office (GAO) was asked to review how the Border Patrol managed its resources, specifically at the southwest border and in particular to examine "the extent to which the Border Patrol has identified mechanisms to assess resource needs under its new strategic plan" (GAO, 2012). In its examination, the GAO found shortfalls. Two key results from the GAO study highlight the challenges that the Border Patrol was experiencing:

- 1) "Southwest Border Sectors Scheduled Agents Differently across Border Zones and Enforcement Activities"; and
- 2) "Data Limitations Preclude Comparing Effectiveness of Resource Deployment across Locations" (GAO, 2012).

The report highlighted that there are multiple factors that Border Patrol agents considered in deploying resources, to include the local terrain, the different types of infrastructure, and the technology available. Ultimately the GAO concluded that the Border Patrol still needs to develop goals and performance measures in order to assess efforts and appropriately allocate resources:

"Given the nation's ongoing need to identify and balance competing demands for limited resources, linking necessary resource levels to desired outcomes is critical to informed decision making ... The establishment of such

goals could help guide future border investment and resources decisions” (GAO, 2012).

The primary challenge in allocating resources is summed up by Christopher Wilson, an associate at the Mexico Institute at the Woodrow Wilson International Center for Scholars, when he stated, “We are talking about measuring illicit activity, which by definition is hidden” (Sukumar, 2013). The RAND Homeland Security and Defense Center published a study supported by the Department of Homeland Security through the National Center for Border Security and Immigration that approaches the problem using pattern analysis and systematic randomness to allocate Border Patrol resources (Predd, Willis, Setodji, & Stelzner, 2012). RAND’s analysis concludes that allocating resources by combining pattern analysis and randomness the Border Patrol will achieve greater interdiction rates than either approach alone. Ultimately however, RAND acknowledged that the value of this approach depends on how well future illegal trafficking flow matches historical flow.

Research suggests that data limitations will provide a continuing challenge to the Border Patrol in measuring effectiveness in order to allocate resources as effectively as they possibly could. Our modeling approach will take a unique perspective over other approaches in attempting to quantify the likely flow of illicit drugs through each POE by mode of transport and by month in order to provide insights into allocating Border Patrol resources.

### **Network Flow Model**

Network flow models have a wide range of applicability to real world problems. They are usually used in airlines, transportation companies, distribution centers, and many other scenarios where something needs to be sent or transported from a source to a destination using a certain transport method. Flow is associated with the network, entering and leaving at the nodes and passing through the arcs. Flow is conserved at each node, implying that the total flow entering a node, either from arcs or external supplies, must be equal to the total leaving the node, either to arcs or to the external demands. The arc flows are decision variables for the network flow programming model. The flow is limited in an arc by the lower and upper bounds on flow. Sometimes the term capacity refers to the upper bound on flow. Such limiting attributes are very important for the formulation of our network flow model (Chinneck, 2001).

## ***Network Flow Modeling Approach and Problem Statement***

Our refined problem statement is *to develop a practical model that can be incorporated into the tools and techniques of the Border Patrol, El Paso area, and offer insights into the allocation of resources to the different Ports of Entry to affect illicit trafficking*. We will utilize a network flow model to represent the illicit drug smuggling network. We label the Sinaloa Cartel as the supplier, their methods of transportation through routes or POE as the arcs or routes, and the U.S. as the demand. Understanding the complexity of illicit drug trafficking, we made a conscious decision to narrow our focus to the El Paso-Juarez area. Narrowing our area of focus is intended to provide better localized results.

### ***Defining the Network***

We identify the source or supply node of our network as being the Sinaloa Cartel in Juarez and the destination or demand node as the U.S. We identify six different routes or arcs representing the main crossing points used by the Sinaloa Cartel to illegally cross the drugs. Each route has different methods that can be used to transport drugs. Figure 1 shows the network outline of our model. The five methods modeled include Trucks, POVs, Pedestrians, Ultra-light Aircraft, and Tunnels. Each method is modeled as having an average capacity as follows: A = Trucks (120 kg per truck); B = POVs (30 kg per POV); C = Pedestrians (3 kg per person); D = Ultra-light aircraft (110 kg per aircraft); E = Tunnels (90 kg per trip). Some methods are not employed on some routes. Methods of transportation for each route are as follows:  $i(1) = A, B, C$ ;  $i(2) = A, D, E$ ;  $i(3) = B, C$ ;  $i(4) = B$ ;  $i(5) = A, B, C$ ;  $i(6) = A, B, C$ .

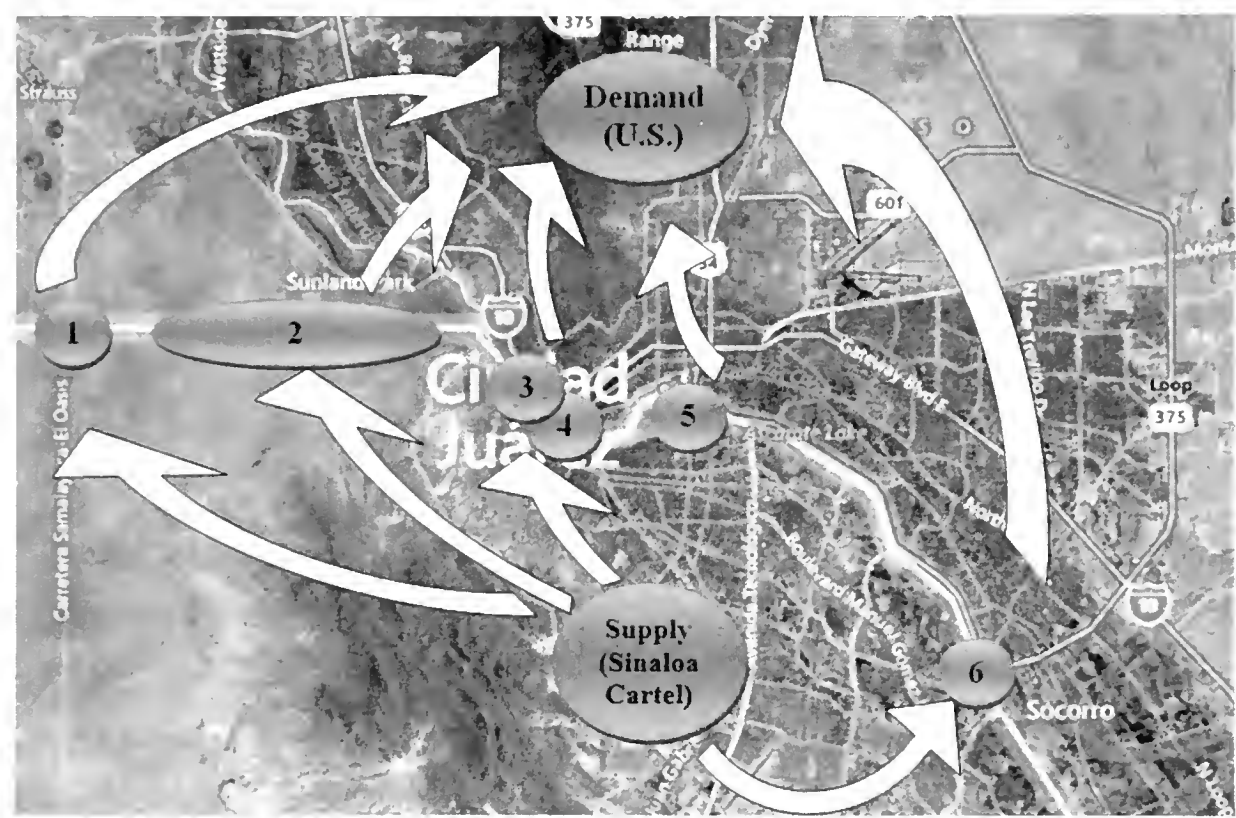
The maximum capacity for each route by method is modeled as the largest month of the year. For example, in the Paso del Norte POE (route 3) the maximum number of pedestrians that crossed in 2011 is 358,277 in December, which gives the upper bound for the pedestrians in route 3. We modeled the maximum capacity of each of the methods by month for each of the routes this way. Once we identified all the routes, methods of transportation, and the capacities for each, we developed the linear programming of our network flow.

### ***Decision Variables***

The decision variables will change in order to maximize the objective function. In this model, the decision variables are the amount of drugs the cartels are able to smuggle through each route organized by

method of transportation and month. The total amount of drugs at each route is a sum of the drugs smuggled by each method of transportation used and the month of the shipment. They are represented by each leg, or arc, in the maximization flow network.

$X_{ijk}$  = Amount of drugs in kilos sent through route  $i$  by  
method of transportation  $j$  during month  $k$



- Supply (Sinaloa Cartel)

$i(1)$  = Santa Teresa, NM, POE

$i(2)$  = Anapra Vicinity

$i(3)$  = Paso del Norte POE
- Demand (U.S.)

$i(4)$  = Stanton POE

$i(5)$  = Americas POE

$i(6)$  = Zaragoza POE

Figure 1. Network Outline

The costs along these arcs are usually modeled as a function of actual cost in dollars. However, it is very difficult to gather accurate information regarding the costs that cartels spend transporting the drugs. Instead we model cost as *gain* (in percentage). For example, the cartels have a higher risk of losing their drugs if inspections at the POE are stricter, which could be represented with a lower *gain* percentage. If



inspections are quick and not enforced, there is a lower percentage of getting caught, which is represented with a higher *gain* percentage. For example, if we analyze the data, February seems to have very low traffic in the official POE. Low traffic volume allows the CPB agents to conduct more meticulous inspections. The cartels have a higher risk to get caught and a lower *gain* value. During Christmas time, there are a lot of people traveling in and out of the U.S. Border Patrol agents are required to keep inspection times to a minimum since people trying to cross to the U.S. may take up to three hours waiting in line to get inspected. Then, there is a lower risk to get caught and a higher *gain* value.

As an example, 200 metric tons of drugs were seized from the 378 metric tons estimated to have been shipped to the U.S. from South America in 2009 (United Nations Office on Drugs and Crime, 2011). We use this approximation of 53% loss in seizures to model the *gain* value in our formulation.

We assumed that each POE will reach a maximum *gain* value of 100% when it is at its maximum capacity (busiest), and a *gain* value of 47% when it is at its lowest capacity (slowest). Any capacity between the lowest and maximum capacity will be calculated with a linear relationship between those two values. As an example, at the Americas POE (route 5), February had the fewest number of trucks, POVs and Pedestrians through the route during the year. It is assumed that the Border Patrol is able to be more meticulous with inspections during the slower months leading to a higher likelihood of interdiction, and in turn less *gain* for the traffickers. The *gain* assumed is only 47% for each of these methods in February. The busiest month for Trucks and POVs is August resulting in a 100% *gain* and the busiest month for Pedestrians is December resulting in a 100% *gain*. Each other month's *gain* is derived based on the relative monthly volume of traffic by method. This process is applied to every month and method of transportation at every route.

### ***Objective Function and Constraints***

The objective of the network flow is seen through the cartel point of view. In order for the Border Patrol to optimize its allocation of its resources, whether it is money, manpower, or any other resource, they have to be able to anticipate the cartel's move. It is more convenient to create a model that mirrors the cartel's rational course of action, which is to maximize its revenue. Therefore, our model will maximize the amount of drugs being smuggled into the U.S. The principle equation of our



network flow model follows.

$$\max: \sum_{i=1}^6 \sum_{j=1}^5 \sum_{k=1}^{12} g_{ijk} * x_{ijk} \quad (1)$$

In equation (1),  $g$  is the *gain* value and  $x$  is the amount of drugs being transported to the U.S. in kilograms (kg) by each route, method of transportation, and by month. We will utilize the maximized decision variables from each route for the analysis. For example, once we run the network flow model in a linear program, we will be able to see the amount of drugs being smuggled at each node per method of transportation per month. We can use that information to compare it with the optimized amount from all other nodes and see where and when the drugs are being shipped. We can compare the data from each route to see where it may make sense to allocate more resources each month.

An important assumption is the initial amount of drugs the Sinaloa Cartel is trying to ship. As discussed previously, the 2011 World Drug Report estimated that 53% of the total drugs is seized. If the Border Patrol was able to seize 27,482 kg in fiscal year 2010, we can assume that the initial amount of drugs that the cartels have to cross to the U.S. is 51,853 kg. Since we don't know the actual route(s), month(s), and method(s) of transportation the Sinaloa Cartel used to smuggle the 24,371 kgs successfully into the U.S., we assume that the cartels equally distribute the drugs per month and per route in order to keep up with the demand in all areas of El Paso. Consequently, we used the amount 339 kg per route per month ( $Limit_{ik}$ ).

These are the final constraints:

$$x_{ijk} \leq Capacity_{ijk} \quad (2)$$

$$\sum_{j=1}^5 x_{ijk} \leq Limit_{ik} \quad (3)$$

$$x_{ijk} = d_j * Xunits_{ijk} \quad (4)$$

Equation (2) ensures that the amount of drugs crossed through each route is not greater than the capacity of each route. Equation (3) limits the amount of drugs transported due to the initial supply of the cartel, and equation (4) converts every unit of transportation into amount of drugs the cartel smuggles in kilograms depending on the capacity of each method of transportation (d). As a final constraint, we assumed non-negativity for our  $x$  variables.

### ***Method for Solving and Results***

Although this initial network flow model is simplified with only two nodes and can be solved in Microsoft Excel, we chose CPLEX. IBM ILOG CPLEX is a high-performance mathematical programming solver for linear programming. Its technology enables decision optimization for improving efficiency, reducing costs, and increasing profitability (IBM, 2013). CPLEX gives the opportunity to easily adjust the decision variables, objective function, and constraints to make changes to the model. This software can be used in the way ahead by adding many more constraints and decision variables since IBM ILOG CPLEX Optimizer has solved problems with millions of constraints and variables (IBM, 2013). With the intent to expand the network flow structure in future work, we used CPLEX as the method for solving this optimization problem.

We set up the linear program to have the optimal solution output both amount of drugs in kilograms crossed into the U.S. and the units of each specific method of transportation being utilized to cross the drugs. Analyzing the output associated with our decision variables ( $X_{ijk}$  = Amount of drugs in kilos sent through route  $i$  by method of transportation  $j$  during month  $k$ ), can provide insights into the likely methods of transportation used each month at each route which in turn can aid the Border Patrol to focus their inspections in either the truck line, POV line, or the pedestrian line at a given POE. Figure 2 shows example output results.

Output results for November show that at routes 1, 4, and 6, traffickers will maximize their gain by smuggling through the POV line. In turn, CPB should focus their inspections more in the POV line. They should have extra manpower, sniffing dogs, or other resources available in those POV lines. Route 2 will experience some activity in the truck line and there is the possibility of a run through a tunnel in the Anapra vicinity. Routes 3 and 5 will have more activity in the pedestrian line of those two POE. Our model will provide the Border Patrol with viable insights to focus their inspection efforts and allocation of resources on a specific method of transportation.

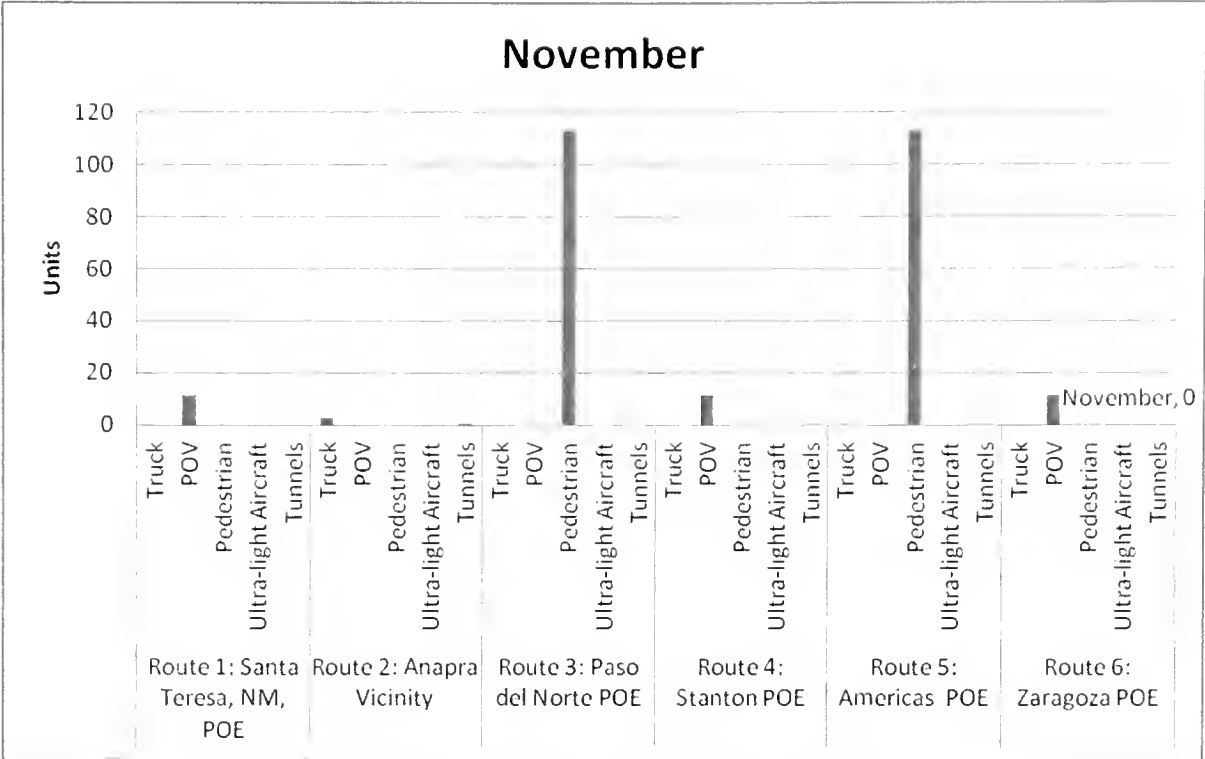


Figure 2. Total Units Utilized in November.

Conclusion and Way Forward

Network flow modeling has the potential to be a useful approach in allocating resources to combat illicit trafficking. This effort addresses a simplified network flow model in which the results are intended to provide Border Patrol agents insights into likely methods of transporting drugs through six primary transportation routes from Juarez into El Paso. We can compare and contrast every method of transportation at every route each month to see where they need extra manpower or other resources to better interdict drugs. This will allow the Border Patrol to successfully allocate their resources to fight against the Sinaloa Cartel.

This approach can be expanded and adjusted for more robust data or different areas. Our next step in this effort is to continue incorporating more robust data and assumptions into our model for more accurate findings. We can forecast that the Sinaloa Cartel will continue to take over the Juarez Plaza, while analyzing their methods of transportation and their rationale used to decide where and when to ship their drugs into the U.S. Improving the *gain* value used in this model is essential for further and more accurate results. This might include more research about what risks the Sinaloa takes into consideration before shipping a load. Do they care if

they lose a couple of kilos? Do they really have unlimited resources? All of these questions are crucial to develop a more accurate *gain* value. In addition, this model only applies to the El Paso-Juarez border; however, with further research, it can be developed to model the entire El Paso Sector and one day to the entire Mexican border. Despite the limitations, we are confident that this practical model provides useful insights to the Border Patrol, El Paso area, to better allocate their resources.

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## **Bios**

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**LTC Elizabeth Schott** is an Academy Professor in the Department of Systems Engineering at the United States Military Academy at West Point, NY.

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# Future Directions for the U.S. Research and Innovation Enterprise

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**Council on Competitiveness, Washington, DC**

## **Abstract**

Tectonic shifts in technology and the global economy have reshaped the competitive landscape, and driven a deep transition in the world order of production. These shifts are creating an urgent need to rethink U.S. approaches to research and innovation in support of the American economy and continued U.S. global leadership in the 21st century. This presentation highlights some of these technological and competitive game-changers, and the opportunities and challenges they present. It offers key insights gathered from Council on Competitiveness engagements with the Nation's technology and business leaders on how our research and innovation enterprise must change for this new economic age. This includes critical areas ranging from R&D investment, research management and entrepreneurship, to training American scientists and engineers, technology transfer and commercialization.

**IT IS A PLEASURE TO BE HERE** and an honor to have been asked to deliver remarks for the AAAS 40<sup>th</sup> Anniversary Distinguished Speaker Series. The Fellowships program plays an important role in providing scientists and engineers an opportunity to see first hand how government shapes science and technology. The program also imparts vital skills, helping scientists and engineers learn how to better integrate their knowledge and research into political, economic, and social contexts. For ultimately, it is the challenges, problems, and opportunities in these arenas that science and technology must address to have its greatest value.

My remarks will focus on the changes sweeping across the competitive landscape, how these changes are creating an historic “moment in time” and an Innovation Imperative for the United States, and the role of our science, research, and innovation enterprises in meeting them.

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This presentation was the keynote and concluding address for the 40<sup>th</sup> Anniversary Distinguished Speaker Series of the Science and Technology Policy Fellowships Program at the American Association for the Advancement of Science (AAAS) on December 16, 2013. Throughout 2013, the series featured noted scholars, scientists, and policy leaders sharing their insights and discussing today's most compelling science policy issues — issues with implications from national to global perspectives.

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## Changing Competitive Landscape

We are in the midst of a deep transition in the world order of production — an era of turbulence, transition, and transformation — and we are grappling with the new realities of a transformed global economy. The digital revolution has been an epochal force of change, accelerating the integration of the world's economies. Over the past 20 years, the amount of money flowing across borders grew at more than three times the rate of global GDP. Internationally traded financial assets<sup>1</sup> have soared by a factor of twelve. International trade and foreign investment have more than tripled. Global data flows are projected to triple over the next five years.<sup>2</sup>

The most important resources for production — knowledge, technology, capital, and skills — are all highly mobile. All aspects of industrial production have been transformed, and supply chains wrap around the world. For example, companies in seven nations across three continents contributed to the production of the Boeing 787 Dreamliner. The supply chain for the U.S. Olympic Snowboarding team's uniforms stretched across six countries and three continents: they were designed in Vermont; the competition fleece was woven in Italy; waterproof corduroy pant fabric was developed in Taiwan and sewn in Vietnam. Final fabrication was done in Japan, and China produced accessories.

For emerging and developing economies, this era of change has enabled rapid economic gains. Globalization and the digital revolution have shattered the traditional economic development curve. The digital revolution gave developing economies access to modern production knowledge and tools, and access to the world's businesses, supply chains, markets and jobs. More than half of foreign direct investment (FDI) now goes to emerging economies, up from 20% in 2000 — a huge boost in about a decade.

As a result, we see developing countries evolving rapidly from resource- and commodity labor-based economies to knowledge and skill-based economies, leaping toward convergence with the developed world. Globally competitive high-tech industries have emerged in countries such as Korea, the UAE, Columbia, India, Brazil, and Mexico.

We have evolved into a multi-polar science and technology world. Two-thirds of global research and development (R&D) is performed somewhere other than the United States, and game-changing technologies can originate almost anywhere: Australia leads the world in quantum



computing. The Rhône-Alpes is a major bioscience center. Ireland a world leader in financial services software. The Czech Republic is coming on in low-cost electric vehicles. Singapore is growing a hub for water-related research and business. The National University of Singapore and Nanyang Technology University rank as the world's #1 and #2 water research institutes. In just five years, China doubled its R&D investment to more than \$200 billion, becoming the world's second largest investor in R&D. And with its purchase of 128 advanced genome sequencers, the Beijing Genomics Institute alone now has more DNA sequencing capacity than all of the NIH-supported genome centers combined.

Knowledge, information, and technology are widely distributed, increasingly commodities, and accessible globally. So rewards do not necessarily go to those who have a great deal of these things. Instead, rewards will go to the countries, companies, and people who know what to do with these building blocks once they get them.

This has created an "Innovation Imperative" for the United States.

### **Significant Opportunity on the Horizon**

While countries around the world have shifted into competitive high gear, there are tremendous opportunities unfolding for the United States.

#### ***Energy Revolution and Manufacturing Transformation***

Manufacturing and energy are tightly interlinked, and at their intersection lays an historic opportunity for the United States. Manufacturing is vital to U.S. economic and national security, and our leadership in technology and innovation which is the very foundation of America's prosperity, standard of living, global leadership and influence. This vital role has driven the United States for decades to focus on reviving our industrial engines. The Council's [on Competitiveness] **Manufacturing Competitiveness Initiative** took stock and saw the makings for a 21<sup>st</sup> century American manufacturing renaissance.

U.S. manufacturing is growing, and leading our recovery, last year growing three times faster than the overall economy. Manufacturing is our global market engine, accounting for 60% of U.S. exports. It has the highest multiplier effect of any industry. For every \$1 in manufacturing value added, \$1.40 in additional value added is created in other sectors of the economy. U.S. producers remain at the technological frontier, and we have the world's largest set of high-tech manufacturing industries. U.S.

manufacturers drive U.S. innovation, accounting for 45% of our national R&D investment and 70% of private R&D, much of it focused on developing new technologies and products for global markets. Today, high-tech infuses every step of designing, developing, fabricating, delivering, and servicing U.S. products.

Energy is the lifeblood of the industrial enterprise. The Council's **Energy Security, Innovation, and Sustainability Initiative (ESIS)** brought this tight linkage between energy and manufacturing competitiveness into sharp focus. In the ESIS, we saw the potential to increase U.S. manufacturing productivity through greater energy efficiency, and to boost manufacturing competitiveness through the production of new forms of energy and energy-efficient products.

Remarkably, the stars have aligned for us in the energy space, creating a once-in-a-century opportunity. Just five years ago, the tone of the Nation's energy conversation was all doom and gloom, centered on how we would deal with energy scarcity and long-term threats to our energy security. The tone of that conversation has changed dramatically. It's now centered on energy abundance and strength, and how to seize emerging energy opportunities to revitalize the industrial base. Relatively overnight, the energy landscape transformed radically, and the headlines herald the United States as the world's largest producer of petroleum and natural gas. Treasure troves of U.S. natural gas and oil have been unlocked by new technologies. Proved reserves of U.S. oil and natural gas in 2010 rose by the highest amounts ever recorded since the U.S. Department of Energy (DOE) began publishing reserve estimates in 1977. Earlier this year, the U.S. Geological Survey tripled its estimate of technically recoverable natural gas in the Bakken and Three Forks Formations,<sup>3</sup> and doubled its estimate of recoverable oil there. A few years ago, U.S. industry was investing in facilities to import natural gas; now we are becoming a major natural gas exporter. Employment in the U.S. oil and gas industries has increased 40% in just five years (from 2007 to 2012).

Historically low natural gas prices are luring manufacturing back to the United States and providing U.S. energy-intensive industries — such as chemicals, plastics, and steel — a critical cost advantage. According to the International Energy Agency, natural gas prices are roughly five times higher in Japan, three times higher in the European Union (EU), and two times higher in China than those in the United States. And industrial consumers in Japan and the EU are paying more

than twice as much for electricity than U.S. producers pay; even Chinese industrial consumers pay almost double the U.S. price.

But there is more good news ... there is a large and growing market opportunity. Today's energy and sustainability challenges have created a perfect storm for energy innovations at every scale. The world is thirsty for cleaner energy. Last year, a record \$269 billion was invested globally in clean energy technologies — a five-fold increase since 2004 — and trillions of dollars will be invested in the decades ahead. Energy and energy efficiency innovations are needed in transportation, appliances, equipment, green buildings, materials, lighting, fuels, power generation, industrial processes, and consumer goods.

These developments have unfolded with breathtaking speed and scale. American manufacturers have a golden opportunity to move to a new era of industrial transformation, sustainability, energy innovation, and market opportunity ... a chance to grab a big brass ring, if we seize the moment.

This dramatically-changed energy landscape was the catalyst for a new partnership between the Council on Competitiveness and DOE. We launched the American Energy and Manufacturing Competitiveness Partnership to: (1) ignite efforts across the country to increase U.S. competitiveness in the production of clean energy and energy efficient products; and (2) increase U.S. manufacturing competitiveness across the board by increasing energy productivity, and taking advantage of low-cost domestic energy sources.

To gain insights drawn from real world experiences, we have carried out a series of dialogues across the country that engaged hundreds of stakeholders from industry, academia, labor, and government. Through these dialogues we are defining barriers and challenges. We are taking a hard look at issues ranging from high capital requirements and lack of innovation infrastructure to structural costs and low investment in advanced manufacturing technology. We are generating solutions and examining models for the public and private sectors to work together to solve problems, and putting these models and solutions in place.

Just last week, we convened the first ever **American Energy and Manufacturing Competitiveness** (AEMC) Summit. The AEMC Summits are a launching pad for a national conversation and a singular catalyst for national momentum to leverage the critical nexus between energy and manufacturing. At the first Summit, we released *Amplify* — a call to

action for the Nation to build on this distinctive time in history to dramatically strengthen our energy, manufacturing, and economic competitiveness. **Amplify** outlines two public-private partnership models that could significantly increase the competitive production of clean energy and energy efficient products in the United States:

- The **Manufacturing and Energy Technology Accelerator** would be a new platform designed to connect the Nation's world-class innovation institutions to facilitate the transition of clean energy technologies into products, processes, and scale manufacturing.
- The **Clean Energy Materials Accelerator** would reduce the risks of deploying new materials in commercial products and processes by creating a platform to address common challenges, by increasing access to materials qualification and characterization tools, and by creating standards for advanced materials.

### **Technological Revolutions**

At the same time that the manufacturing and energy landscape is tilting in our direction, a new age of unprecedented knowledge, unparalleled technological power, and inconceivable innovation is unfolding. We are on the cusp of profound technological change. The digital, biotechnological, and nanotechnology revolutions are rewriting the rules of production and services in digital code, genetic code, and atomic code.

#### ***Biotechnology***

We are at an inflection point in the commercialization of biotechnology. The cost of DNA sequencing has fallen through the floor — down a hundred-thousandth in a decade, a drop steeper than decreases in the cost of computing power. It took 13 years and \$3 billion to sequence the first human genome. By 2001, the cost of sequencing a genome had dropped to \$100 million. Last year, the cost dropped to \$10,000. The cost is expected to drop to \$1,000 this year. To sequence a mega-base (1 million bases) of DNA in 2002, you needed more than \$5,000 and several weeks of manual labor to do it; today, you can do it for 19 cents and a few hours of machine time. These remarkable cost reductions change everything in the biotech business, and should open the floodgates of innovation.

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### *Nanotechnology*

Nanotechnology is coming of age. Lux Research estimates that global sales of products containing some nanotech components could reach \$2.4 trillion in 2015. Nanotechnology is likely to drive a reordering of production and industry as significant as the change brought about by digital technology — affecting all materials, manufacturing, medicine, energy, food, and warfare.

### *Digital Technology*

The digital revolution has reshaped the world more profoundly and more rapidly than any other technological development. Its second stage is now unfolding — characterized by ubiquity, mobility, and big data.

Ubiquitous computing<sup>4</sup> and the Internet of Things are evolving rapidly: Machine-to-machine technologies are being used across a broad spectrum of industries and applications. Machine-to-machine data traffic is expected to grow nearly 90% annually between 2012 and 2017. It has been estimated<sup>5</sup> that, in the decade ahead, more than 50 billion things will be connected to the Internet, and \$14 trillion in economic value at stake in increased revenues and lower costs for businesses.

The digital revolution has gone mobile: There are 6.8 billion mobile phones in use.<sup>6</sup> Cisco predicts that the number of mobile-connected devices will exceed the world's population by the end of the year. This ubiquitous penetration makes mobile devices a key, if not THE, emerging platform for service delivery — in everything from entertainment and legal guidance to health care, financial services, and education.

This is the era of the “Data Tsunami.” We are swimming in sensors, click streams, smartphone traffic, digital transactions, texts, bar scans, email, images, video — and drowning in data. Big data is gushing in extreme volume, at extreme velocity, and in extreme variety ... entering systems at a rate that follows Moore's Law, doubling every two years.<sup>7</sup> We are data rich and insight poor, but big data and data analytics are the next frontier for innovation and competition.

Big data is driving a profound transformation in research — a rare and unique opportunity to revolutionize how discovery takes place, and pursue fields of inquiry that otherwise would be impossible. Think of the health care big data pool. It is filling with: pharmaceutical R&D, clinical data, activity and cost data, and data on behavior. And it is diverse data: images, phenotypic, epidemiological, molecular, cellular, chemical,

clinical, and more. This big data will allow data-intensive research and decision-making at a level never before imagined.

In addition, sensorization and autonomous systems will provide other unprecedented tools for persistent scientific observation and data collection, in a diverse range of environments, at increasingly lower cost. With the world's largest R&D investment, and the world's largest research enterprise — broad in its scope of disciplines — the United States is well positioned to exploit data-intensive R&D, and to capture opportunities for innovation resulting from accelerated discovery, and new fields of inquiry that these data make possible. These mega economic and technological trends will generate trillions of dollars of wealth and millions of jobs globally. They create unprecedented opportunities for the United States ... for innovation, for global market shares, for a renaissance of U.S. manufacturing, and for economic growth and new jobs.

### **Insights from the Technology Leadership and Strategy Initiative Dialogue**

For the past three years, the Council has engaged in a dialogue with America's Chief Technology Officers (CTOs), and their peers at research universities and national labs. Our **Technology Leadership and Strategy Initiative** (TLSI) is designed to better understand today's global technology landscape. The CTOs focused on the Innovation Imperative, and said that we will not retain our leadership in science and technology using skills and models of the past. They focused on the key question: "How can we increase the speed AND volume of our science and technology moving from the laboratory to the marketplace?"

### ***Focus of the Research Enterprise***

The CTOs made clear their continued support for discovery research. However, they are convinced that a greater share of basic research should be informed by the pull of national priorities or strategic technologies that would boost U.S. competitiveness and create jobs. Other countries are driving their competitiveness around technological innovation, and we are not reacting to the hunger these countries have to compete and grow their economies. For example, Chinese supercomputing centers are focused on innovation in the private sector. They are using these machines to develop indigenous technologies in key industrial sectors such as aerospace, energy, materials, biotech, and health care. This is not happening in the United States.

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## *Commercialization*

A great deal of discussion has focused on commercialization. One CTO commented, “We have so much stranded invention compared to other countries, it’s unbelievable.” CTOs believe that a great deal of research at universities and government labs has potential value to meet private or government demand. But, in those cases, the commercialization process has underperformed — hampered by policies and practices that too seldom spark collaboration with industry, often fail to bring key skill sets into the process, and impose burdensome costs and delays. They noted that the basic model for technology commercialization has not changed much since the days of the Bayh-Dole and Stevenson-Wydler Acts. They suggested that the classic tech transfer model was outdated and inherently un-scalable. They noted that universities have broad research complexes, ranging from anaerobic chemistry to zoology. But even a good-sized tech transfer office would struggle to connect this research to opportunities in industry for commercialization. One participant commented that:

“In most laboratories, an R&D agenda is carefully formulated. We identify problems to tackle, get our researchers together, and develop an agenda. We engage the tech transfer people downstream rather than up front, so they typically work independently and sequentially. Somewhere along the line, the tech transfer folks find out about a research invention, usually through in-house review processes, and often after the invention’s been made.”

The participants believe that:

- the early innovation process should be more informed by commercial and production considerations;
- we must connect intimacy with the marketplace to the discovery process; and
- we must connect R&D earlier to potential applications, and then to the back-end of the innovation process that involves the investment and assets of the private sector.

## *Entrepreneurial Skills at Research Universities*

Entrepreneurial skills, or lack of them, were cited as a hindrance to commercialization. Very few scientists are equipped to go into business.

They do not know the difference between an S Corp and an LLC. They don't know how to navigate a state or local permitting bureaucracy. Few understand marketing, or managing company finances in a way that could withstand an intense audit. How many could explain to a Chief Finance Officer (CFO) that an idea will pay off and present data that supports that conclusion?

The CTOs believe that all these mismatches ensure that stunning amounts of stellar science and technology could remain tucked in our labs forever.

### **Rise of Multi-Disciplinarity**

Finally, a major theme was that the U.S. research enterprise has been slow to respond to the rise of multi-disciplinarity. Traditional single discipline, single investigator-driven projects remain the overwhelmingly dominant model of university research. Our traditional single-discipline model does not fit well with many of today's big challenges and innovation opportunities: the key enabling technologies; innovation at the intersection of disciplines; development of technological systems; and addressing challenges such as global food, clean water, energy, and sustainability. All are multi-disciplinary in nature.

Moreover, mega markets are emerging around the world. And these markets need innovations that work in the context of the economic, cultural, and social attributes of these nations. Our research professionals should have the ability to enable, manage, and deploy innovation in multi-cultural, multi-lingual environments. The service economy — almost 80% of U.S. employment and GDP — also requires more skill sets in the earliest stages of innovation. The human element of service innovation requires that technical interfaces be designed with experts in behavioral sciences, and business disciplines like management, marketing, and design.

Most corporations have already moved to multidisciplinary research and innovation teams because the problems faced by their customers and opportunities in the marketplace require it. No one organization or discipline has all the necessary resources for high-value innovation across the spectrum of global needs and opportunity. A skill base for driving high-value, game-changing innovation must span the arts, humanities, social sciences, business, design, marketing, finance, and management, as well as the sciences and engineering. We need engineers that think like artists, and artists that think like engineers. We need to



bring the artist to scientific visualization, the materials scientist to fashion, and the cultural anthropologist to market research. Professionals must come out of their disciplinary stovepipes and converge on problems and solutions. We need a “cauldron of creativity,” where talented individuals from all disciplines can collaborate.

We have seen some examples evolving in academia. In some colleges and universities, energy and sustainability are top priorities, and they are breaking down the boundaries between science, engineering, business, public policy, and law to tackle these challenges. The rise of multi-disciplinarity has wide-ranging implications for research universities such as:

- Reforming undergraduate and graduate curricula to create a science and engineering (S&E) workforce with competencies to engage in complex interdisciplinary problems;
- Establishing research budgets and university programs that allow for collaboration across silos; and
- Organizing more research dollars around particular challenges than in disciplinary buckets.

The Council — along with partners Lockheed Martin and the National Academy of Engineering — launched the **National Engineering Forum (NEF)** to address the future of engineering in the United States. NEF is convening regional dialogues with academia, business, government, the media, and students to address issues such as how to develop American engineers versed and skilled in multiple disciplines, and to work with national leaders in shaping U.S. engineering for the 21st century. Participants have focused on a wide range of topics such as:

- Promoting engineering within the creative context of innovation, problem solving, design, and development ... rather than as an act of technical analysis;
- Re-thinking industry - university - labor - national laboratory collaborations to create a more capable cadre of engineers;
- Linking engineering to solving global challenges; and
- Ensuring that undergraduate curricula nurture both deep technical skills and skills in areas such as finance, entrepreneurship, project management, business development, and communications.

The regional dialogues will culminate in a major national event in Washington, D.C. in 2014.

### **Closing**

These are extraordinary times. America is in the midst of a transition between two great ages — from an age in which physical resources were the main factors of production, to an age in which ideas, imagination, and creativity are the most important resources.

The United States has significant advantages in this new age: We lead the world in high-tech manufacturing and technology-infused services. Our supply chains are agile, deep, and diverse. We have a globally unparalleled science and technology enterprise, with \$400 billion in R&D investment annually creating the world's deepest wells of innovation potential. We possess competitively decisive intangibles; our culture of entrepreneurship, risk-taking, and creativity is unmatched around the globe. The energy landscape, and the cost calculus for manufacturing have rapidly tilted in our direction. We are creative-destructors at every level of the economy,<sup>8</sup> and better than most in reorganizing our economy around disruptive technology. This economic dynamism gives us a considerable edge over more sclerotic competitors.

We can look to the past to imagine our future as a Creation Nation. I am trained as an archeologist, and have long had an interest in the role of technology and innovation in the continuum of human civilization. Throughout history, there have been hubs of extraordinary innovation and innovative people. The great civilizations and game changers — from Bronze Age Mycenae and Classical Greece, to Renaissance Florence and the pioneers of the Industrial Age in America — were all innovators, all creators of new science and technology. They were multidisciplinary, and lived on the cutting-edge of art, architecture, philosophy, science, technology, engineering, and medicine. They were caldrons of creativity and crossroads of diverse cultures.

But they did not have today's powerful tools for creativity and collaboration. Imagine the thinkers of Classical Greece with today's research, computational, and data-mining tools. Imagine the artists, architects, and inventors working in the studios of Renaissance Florence with today's platforms for visualization, graphics, digital design, and rapid prototyping. Imagine the Industrial Revolution with tools for mass customization, service-industry mix, advanced materials, and high performance computing.

Now imagine the possibilities if we put these tools, and the skills to use them, in the hands of millions of Americans. These are metaphors for an Age of Ideas, Invention, and Innovation greater than we have ever seen.

## Notes

<sup>1</sup> Bank loans, bonds, and portfolio equity.

<sup>2</sup> Cisco.

<sup>3</sup> North Dakota, South Dakota, and Montana.

<sup>4</sup> Tagging, networking, and managing of objects, machines, and sensors.

<sup>5</sup> Cisco.

<sup>6</sup> International Telecommunications Union.

<sup>7</sup> For Big Data Analytics There's No Such Thing as Too Big: The Compelling Economics and Technology of Big Data Computing, Forsyth Communications, March 2012.

<sup>8</sup> Industry-level; supply chains; firm-level birth and death; jobs markets, jobs, and skills; mix of technology and human capital in the workplace; changing the way work is organized, etc.

## Bio

**Deborah L. Wince-Smith** is President and CEO of the Council on Competitiveness, a group of corporate CEOs, university presidents and labor leaders working to ensure U.S. prosperity (see [www.Compete.org](http://www.Compete.org)).

As a leading voice on competitiveness, innovation strategy, science, technology, and international economic policy, Ms. Wince-Smith spearheaded the groundbreaking National Innovation Initiative (NII) that played a pivotal role in creating a reinvigorated U.S. competitiveness movement. The NII shaped the bipartisan America COMPETES Act, created state and regional innovation initiatives, and brought a global focus to innovation.

Ms. Wince-Smith has more than twenty years of experience as a senior U.S. government official. Most notably, she served as the nation's first Senate-confirmed Assistant Secretary of Commerce for Technology Policy in the administration of President George H. W. Bush. She also served as a Senate-confirmed member of the Oversight Board of the

Internal Revenue Service, and was responsible for administering the nation's tax laws.

Ms. Wince-Smith serves as a director and Board Member of several publicly and privately held companies, start-up technology companies specializing in displays, consumer electronics and medical devices, leading national and international organizations, as well as U.S. Government advisory committees. She currently serves on the Secretary of State's Advisory Committee on International Economic Policy. As a former member of the Board of NASDAQ OMX, she served on the Audit, Compensation and Finance Committees.

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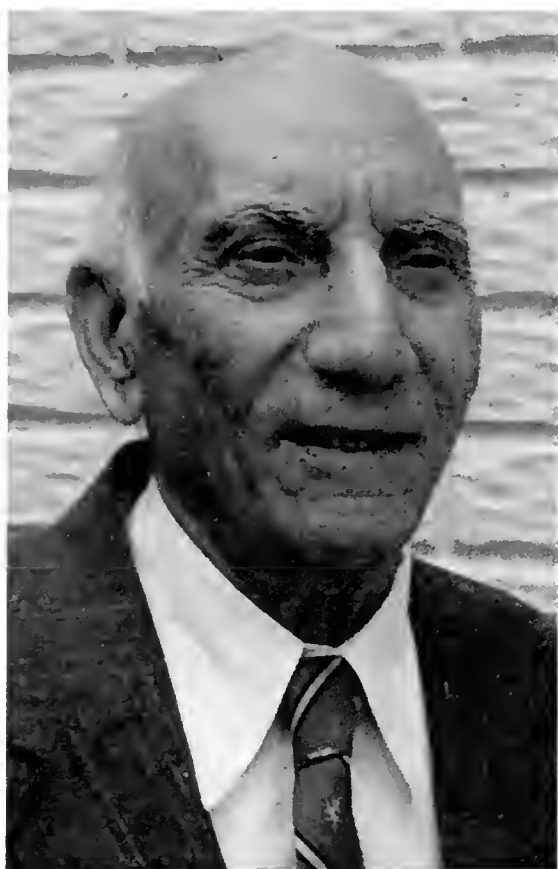
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## In Memoriam

**Dr. Abolghassem Ghaffari**

**(June 15, 1907 - November 5, 2013)**

Renowned scientist Dr. Abolghassem Ghaffari, who had taught at Harvard and Princeton Universities, passed away November 5, 2013 in Los Angeles. He was 106 years old. Dr. Ghaffari was a Lifetime Fellow of the Washington Academy of Sciences (WAS).



In the early part of his career, he was Albert Einstein's colleague at the Institute for Advanced Study at Princeton University under the direction of J. Robert Oppenheimer. On October 12, 2013, he was honored at Harvard University for his lifetime achievements.

Born in Tehran in 1907, he was educated at Darolfonoun School (Tehran). In 1929, he went to France and studied Mathematics and Physics at Nancy University, where he took his L-es-Sc. in Mathematics in 1932. After obtaining post-graduate diplomas in Physics, Astronomy, and Higher Analysis, he obtained in 1936 his doctorate from the Sorbonne (Doctor of Sciences with "Mention tres honorable") for basic research on Mathematical Study of Brownian Motion.

Dr. Ghaffari lectured as a Research Associate at King's College (London University), where he received his Ph.D. from the Mathematics Department on the "Velocity-Correction Factors and the Hodograph Method in Gas Dynamics." As a Fulbright Scholar, he worked at Harvard University as a Research Associate to lecture on Differential Equations and to continue his research on Gas Dynamics.

He was a Research Associate in Mathematics at Princeton University, and at the Institute for Advanced Study, he worked in the early 1950s with Albert Einstein on the Unified Field Theory of Gravitation and Electromagnetism. J. Robert Oppenheimer, who headed the U.S. atom bomb program during World War II, was director of the Institute at the time and interviewed Ghaffari before the latter became a member of the Institute (Oppenheimer later befriended Ghaffari).

Dr. Ghaffari lectured as a Professor of Mathematics at American University in Washington, D.C. and at Tehran University, where he joined the Faculty of Sciences and was appointed full Professor of Higher Analysis from 1941 to 1956.

In 1956, Ghaffari moved permanently to the U.S. to take up a position as a senior mathematician at the National Bureau of Standards. Part of his work there involved calculations of the motion of artificial satellites.

In 1964, three years into the manned space program, he joined, as aerospace scientist, the NASA Goddard Space Flight Center, where he studied the mathematical aspects of different optimization techniques involved in the Earth-Moon trajectory problems, and different analytical methods for multiple midcourse maneuvers in interplanetary guidance. He later investigated the effects of solar radiation pressure on the Radio Astronomy Explorer Satellite Booms as well as the effects of General Relativity on the orbits of Artificial Earth Satellites.

He was awarded in Iran the Imperial Orders of the late Mohammad Reza Shah Pahlavi, and the U.S. Special Apollo Achievement award (1969) at a White House ceremony with President Nixon. He has published more than 50 papers on Pure and Applied Mathematics in American, British, French, and Persian periodicals. In addition to two textbooks, he is author of the mathematical book "The Hodograph Method in Gas Dynamics" (1950).

In 2005, Ghaffari received the Distinguished Scholar award from the Association of Professors and Scholars of Iranian Heritage (APSIH) at UCLA. In 2007, he received a proclamation from former Beverly Hills mayor and current Goodwill Ambassador Jimmy Delshad acknowledging his numerous lifetime achievements. He also recently was appointed as a Hall of Fame inductee by SINA (Spirit of Noted Achievers) at Harvard University. He is also a past member of the Iranian National Commission of UNESCO.



In addition to being a WAS Life Fellow, Dr. Ghaffari was a Fellow of the New York Academy of Sciences and the American Association for the Advancement of Sciences and a member of the London Mathematical Society, the American Mathematical Society, The Mathematical Association of America, and the American Astronomical Society.

He was survived by his wife, Mitra, and his two daughters, Ida and Vida. His one wish was to have a scholarship in his name for young Iranians studying Mathematics or Science. Details about the scholarship may be obtained from his daughter, Vida Ghaffari, at [vidagster@gmail.com](mailto:vidagster@gmail.com).



Tribute to Dr. Ghaffari from SINA (Spirit of Noted Iranian Achievers) at Harvard University, when he was inducted into their Hall of Fame.



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## In Memoriam

**Dr. John H. Proctor**

**(June 3, 1931 - November 28, 2013)**

John Howard Proctor, 82, noted industrial and organizational psychologist, died November 28, 2013. Dr. Proctor was a Life Fellow of the Washington Academy of Sciences (WAS), serving a term as President.



In addition to serving as WAS President and Life Fellow, Dr. Proctor also served as Chaplain, Patrick Henry Chapter #34 Disabled American Veterans (Korean War Veteran); Life Fellow of the World Academy of Arts and Sciences, serving as Secretary General, 1983-1996; Corresponding Fellow of the Royal Spanish Academy of Sciences and a Full Foreign Fellow of the Russian Academy of Sciences. He was a member of the Society for Industrial and Organizational Psychology, Division 14 of the American Psychological Association and Organizational Affiliate of the American Psychological Society and a Diplomate of the American Board of Professional Psychology.

Dr. Proctor worked with several government agencies in the areas of productivity, organization, the war on drugs, change of command procedures, and helped to write the escape and evasion manuals used in the Vietnam War as senior technical advisor to the Air Force at Eglin AFB, Florida. He was the principal in Data Solutions Corporation (1974-1983) and most recently President of John H. Proctor & Associates, LLC. He is the author of four books and over 70 monographs, articles, technical manuals and blogs.

Dr. Proctor earned a BS degree from Davidson College, and a Masters and PhD from Purdue University.

Known for his deep bass voice, Dr. Proctor sang with several choral groups in the Washington area, participating in the recording of Rachmaninoff's Vespers with Maestro Mistaslav Rastropovich. He also sang in Rachmaninoff Hall, Moscow, Russia, in 1991 with the select choir from Columbia Baptist Church in Falls Church, Virginia and performed solos in Moscow, Bryansk and Kyursk, Russia and Odessa, Ukraine, from 1991-2011.

A member of Walnut Hills Baptist Church, Williamsburg, Virginia, he served as an Adult Bible Study teacher, member of the Wednesday morning Men's Prayer Group and the Sanctuary Choir. As an ordained Deacon he began to dedicate himself to missions around the world in his early 60's. His work with Grace Baptist Church, Odessa, Ukraine, and the support of the Children's Shelter and Transition House were his great loves.

Dr. Proctor held the distinction of being the youngest Eagle Scout in North Carolina in the 1940s having to wait a year to be old enough to receive the award.

Dr. Proctor was preceded in death by his daughter Lynn Proctor Parker, his step-son Christopher L. Crye and his parents John C. and Carolyn Hancher-Slade Proctor.

He was survived by his wife Karen (KJ) Boyer Proctor and his children: Susan Carol Proctor King, John Christopher Proctor, James Alexander Proctor, John Boyer Crye and Daniel Danckwerth. He is also survived by his sister, Nancy Proctor Turner, 12 grandchildren, 2 great-grandchildren and several nieces and nephews.

Memorials may be made to the Sanctuary Choir of Walnut Hills Baptist Church, 1014 Jamestown Road, Williamsburg, Virginia 23185, or to the ministry of Grace Baptist Church, Odessa, Ukraine, through the supervision of Walnut Hills Baptist Church.



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